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State of the Universe 1999

**SEU Presentation to the Associate Administrator
Office of Space Science**

May 18, 1999

Volume 1



2043 010251

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AGENDA - Morning Session

The Present, Volume 1

SEU Theme Director's Overview	8:00-8:30	A. Bunner	30 min.
SR&T Program - Balloon Example	8:30-8:45	J. Bock	15 min.
Operating Missions and International Projects	8:45 -9:45	R. Mushotzky	60 min.
<i>BREAK</i>	9:45 -10:00		15 min.
Chandra	10:00-10:30	W. Huddleston	30 min.
Gravity Probe-B	10:30-11:00	R. Geveden	30 min.
Explorers	11:00-11:30	J. Barrowman	30 min.
<i>LUNCH</i>	11:30 -12:30		60 min.

Volume 1: Contents

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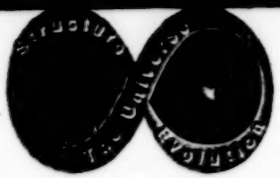
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State of the Universe 1999

Theme Director Overview

Alan Bunner



State of the Universe Report – 2099

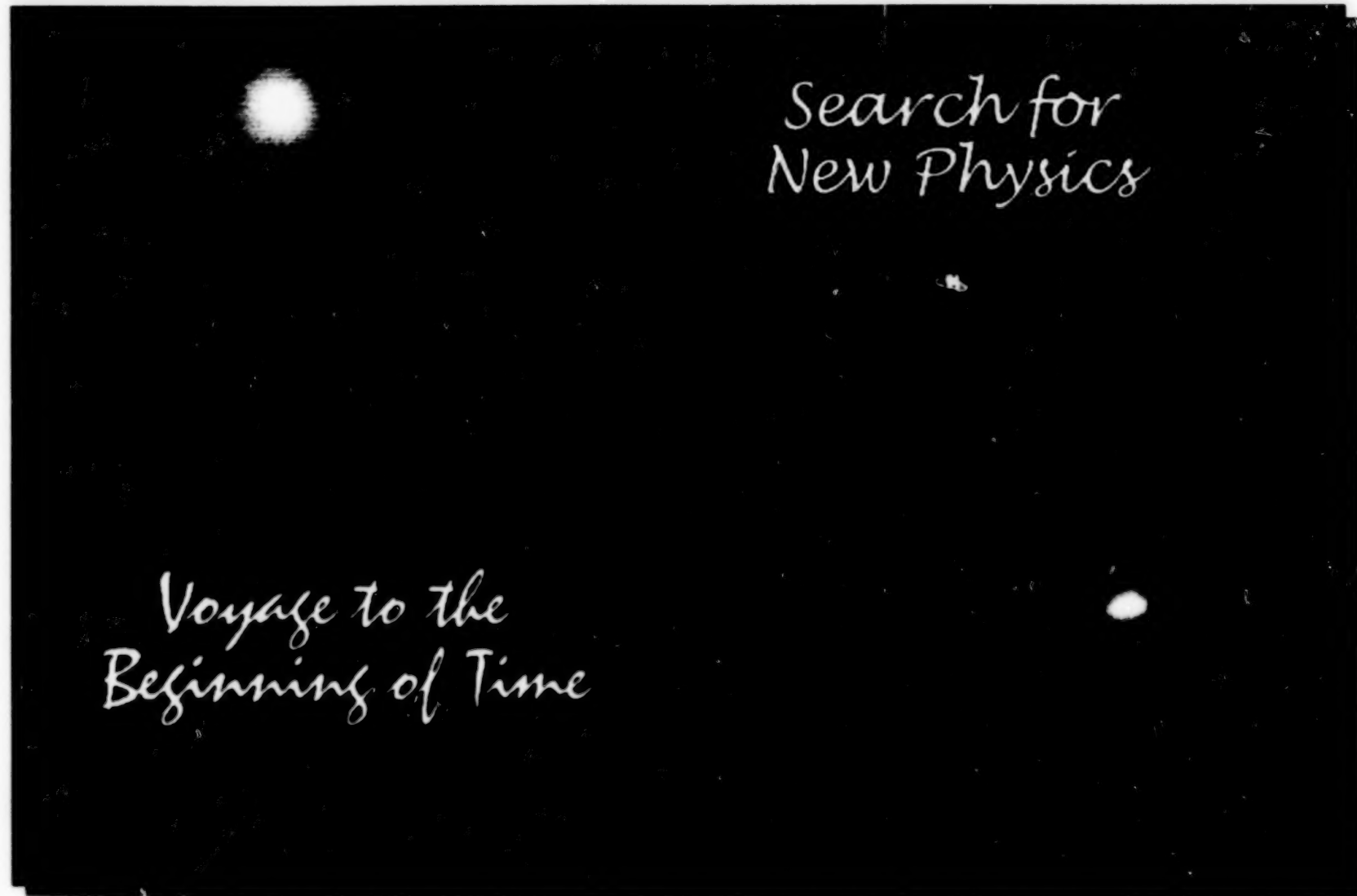
(some possible scenarios . . .)

This past 100 years we have

- Found 2,195 extra-solar planets with nitrogen/oxygen atmospheres
- Observed the seeds of galaxies, super-massive black holes, form at $z = 30$
- Published direct images of black holes, neutron stars, and white dwarfs
- Observed a worm hole at the event horizon of a black hole
- Proved that Einstein's theory of GR breaks down in the strong gravity limit
- Observed gravitational waves from black hole mergers
- Launched a probe to "Dan Goldin 1," the black hole discovered 10 pc from the Sun
- Found "new physics" that enabled the post-Einstein era and interstellar travel. . .



Grand Challenges in the Structure and Evolution of the Universe Theme



Prais'd be the fathomless Universe, for life and joy, and for objects and knowledge curious.

Walt Whitman, 1819-1892



Challenge 1: Voyage to the Beginning of Time

Why is the Universe the way it is, and what is its ultimate fate?

Determine the fundamental parameters of the Universe

When were the elements from which we are made synthesized?

Why do atoms make up only a few percent of the mass/energy content of the Universe?

What is the nature of the Cosmological constant?

What is dark matter?

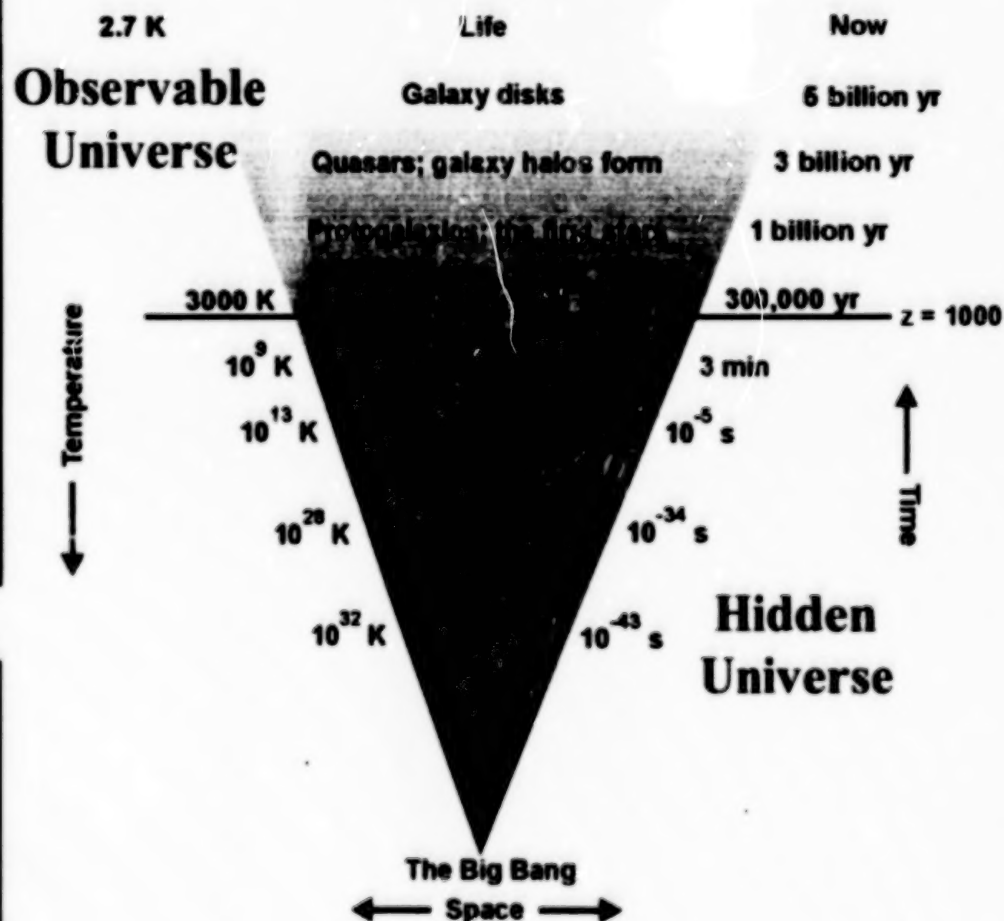
What is the ultimate fate of the Universe?

Is inflation correct?

Search for remnants from the early, hidden Universe

Are there topological defects, e.g., strings and monopoles?

Can gravitational waves from the Big Bang be detected?





How to Voyage to the Beginning of Time

Observe the Universe from the microwave background to the present epoch to test cosmological models to the limit

4,000 square
degrees
containing
about 2 million
galaxies

Make a complete inventory of the contents of the Universe, from the largest structures to the faintest galaxies



3D catalog and simulations of the Universe at all scales



Model all observable structure from initial fluctuations in microwave background

- Measure time dependence of Cosmological Constant
- Determine cosmic abundances at all epochs
- Search for evidence of topological defects, monopoles, cosmic strings
- Detect gravitational radiation from the Big Bang itself

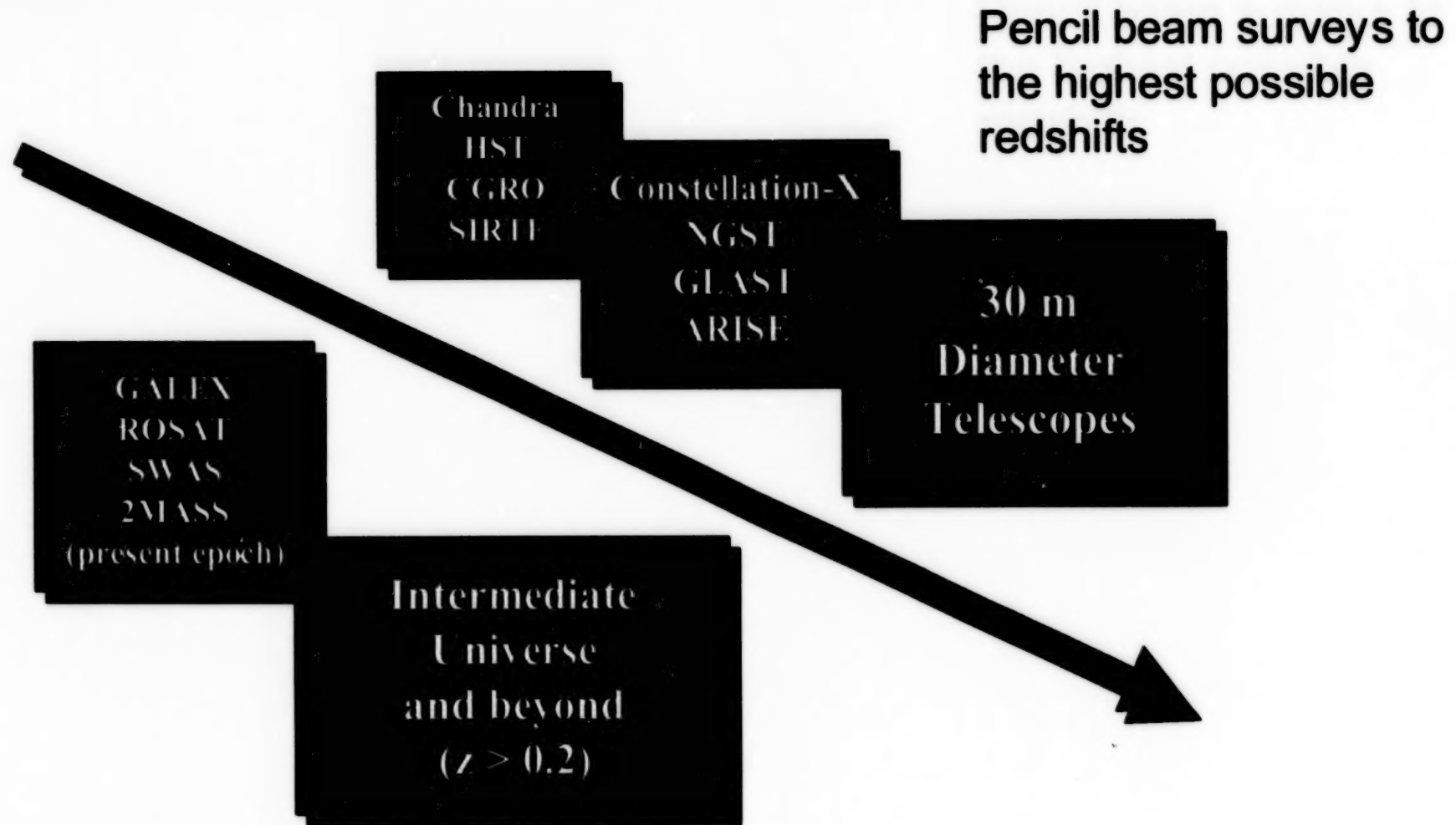
Virtual travel to the beginning and end of time

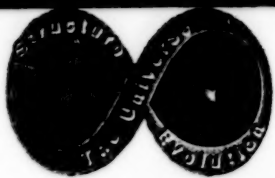
Strings in
the early
Universe

3d simulation
of Universe



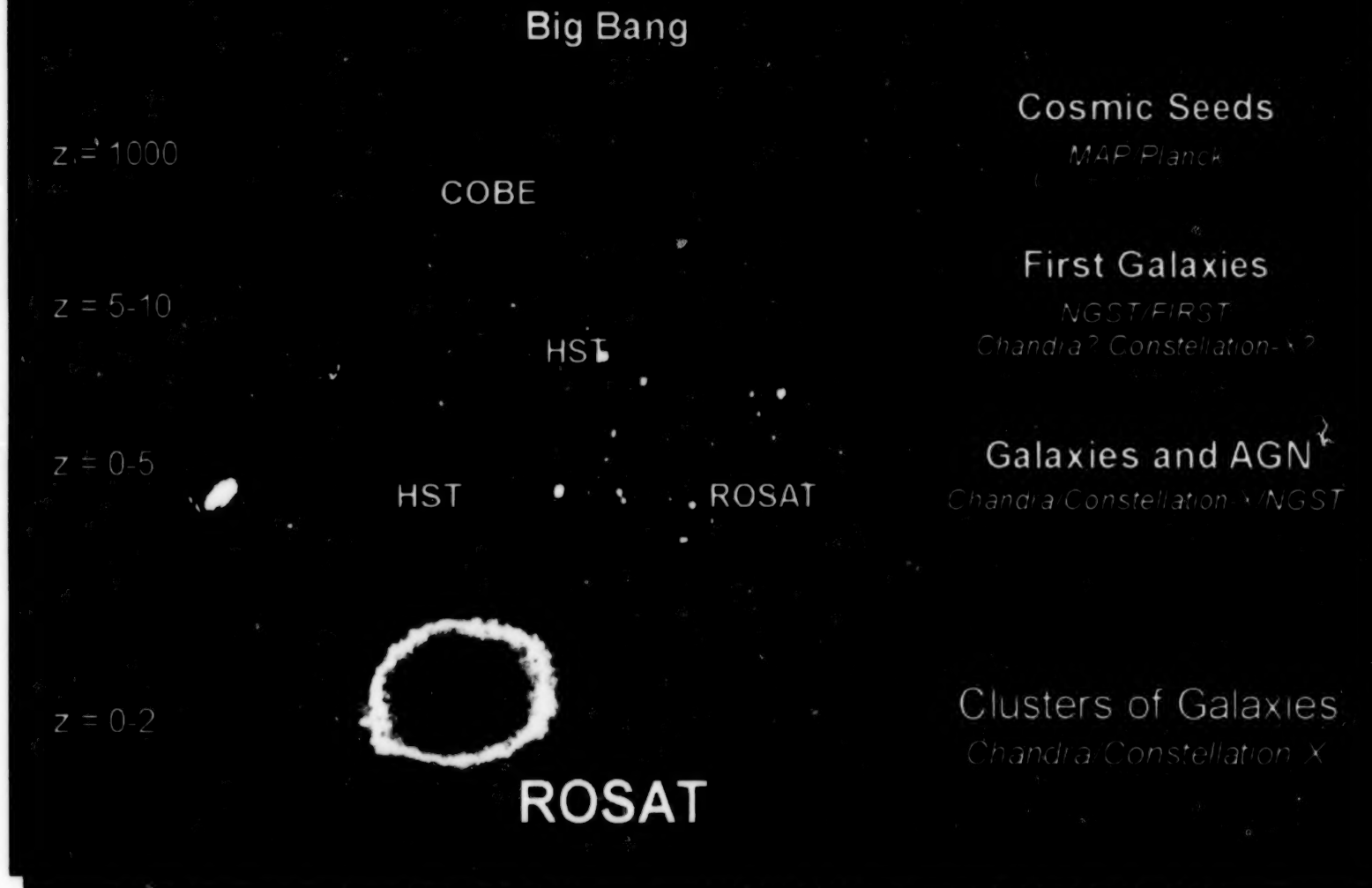
What is Needed to Voyage to the Beginning of Time

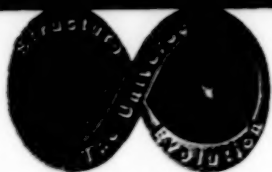




Anatomy of the Universe

Structure in the Universe

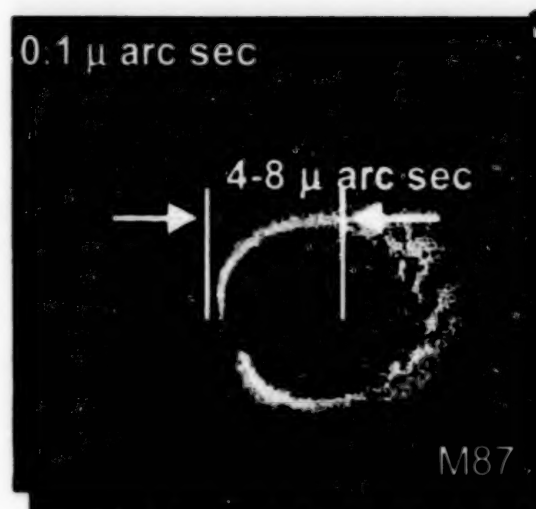
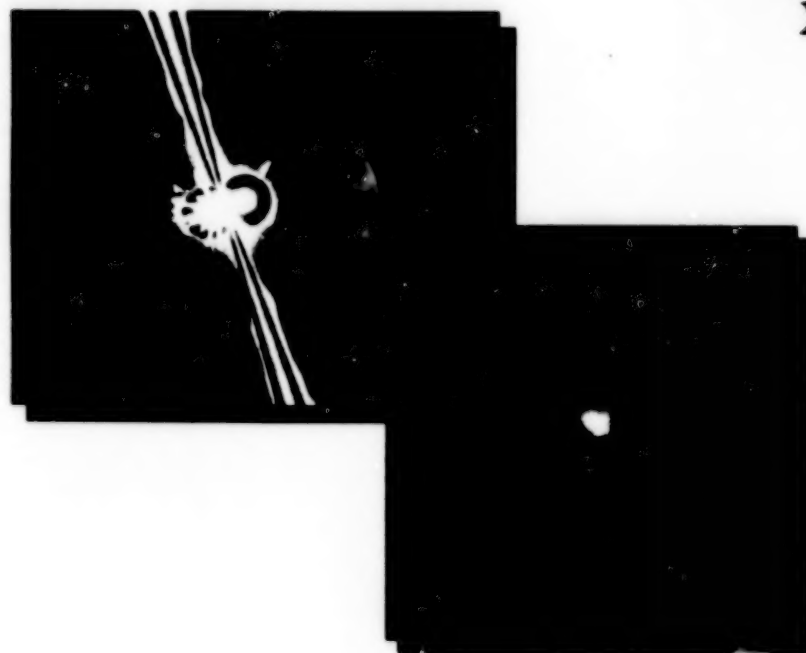




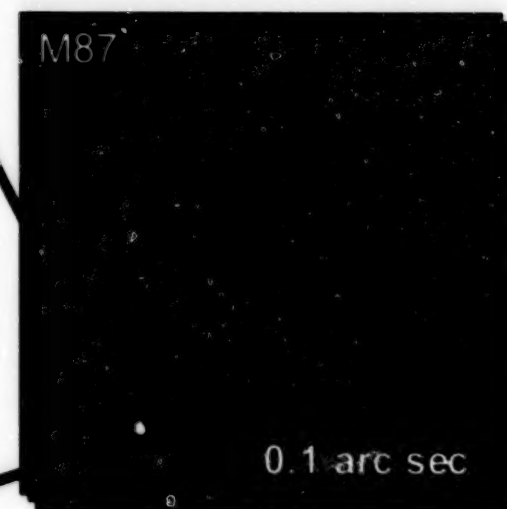
Challenge 2: Search for New Physics

Black holes as gateways to new physics

- A singularity where the known laws of physics break down
- Provide test for “strong gravity” limit of General Relativity
- Confront our understanding of the laws of physics



X-ray Image Simulation



HST Image

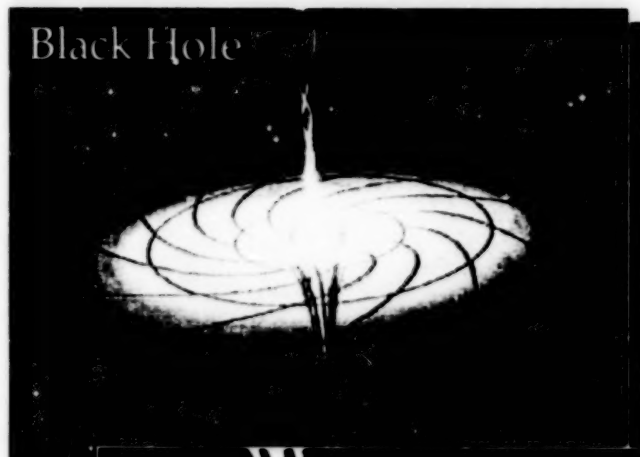
Achieve Grand Unification

- Use cosmic explosions to reproduce conditions found in the early Universe
- Observe the highest energy particles to identify new physical processes
- Space-based tests of fundamental physics, e.g., test the Equivalence Principle

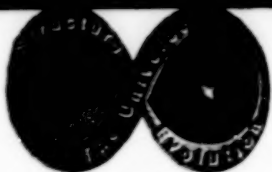


How to Search for New Physics

Use extreme environments in the Universe to test the fundamental laws of physics



- **Use black holes to**
 - Observe strong gravity space-time distortions predicted by General Relativity
 - Test wormhole theories
 - Observe speed of light jet acceleration mechanisms
- **Use the most energetic processes in the Universe**
 - Observe the most energetic Cosmic Explosions (gamma ray bursts and supernovae)
 - Measure highly relativistic outflows
 - Determine the origin of the most energetic particles
- **Use gravitational radiation from binary black hole systems to test general relativity**



Search for New Physics: Journey to a Black Hole

1990-1999

Do Black Holes Exist?

2000-2007

Where are They?

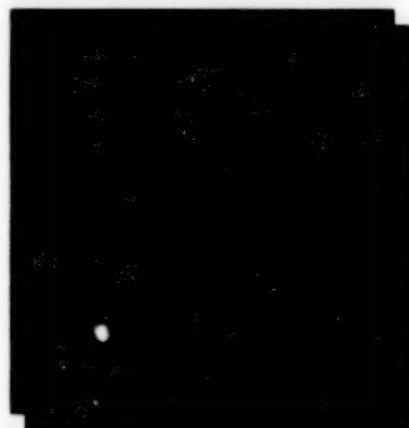
2007-2015

What are They?

2015-2023

The Ultimate Proof!

Explore All Options



ASCA
ROSAT
HST
CGRO
RXTE

Black Hole Survey



Chandra
XMM
Astro-E
INTEGRAL
GLAST
NGST

Black Hole Anatomy



Constellation-X
ARISE
LISA
GLAST

Take a Direct Image

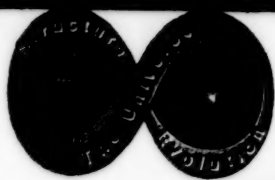


Micro Arcsecond
X-ray Imaging
Mission
MAXIM

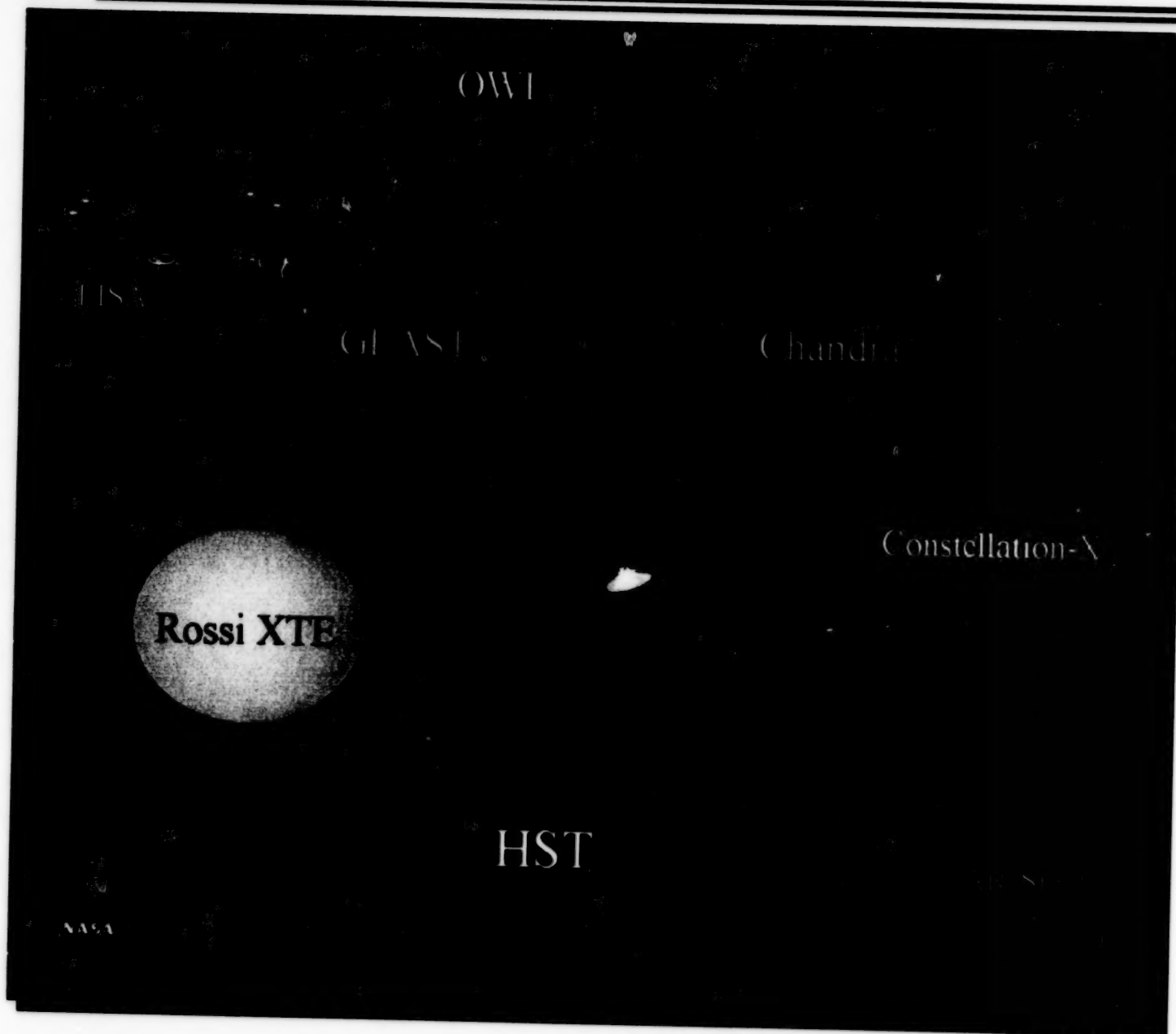


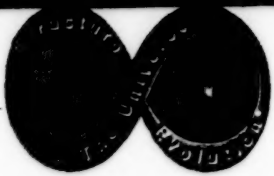
Anatomy of a Black Hole





What the Missions Accomplish

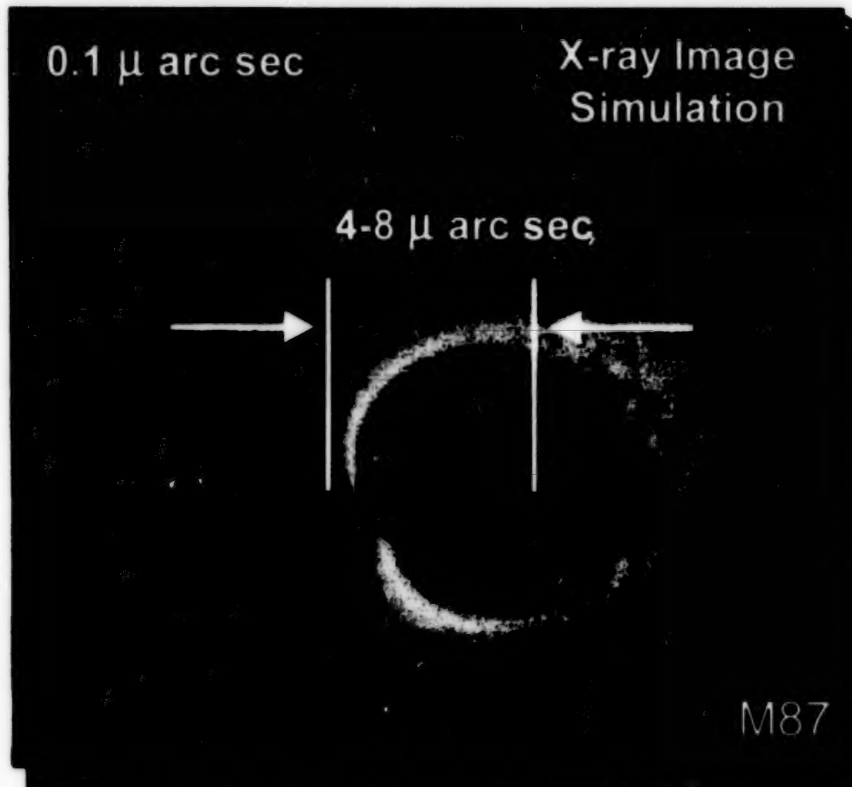
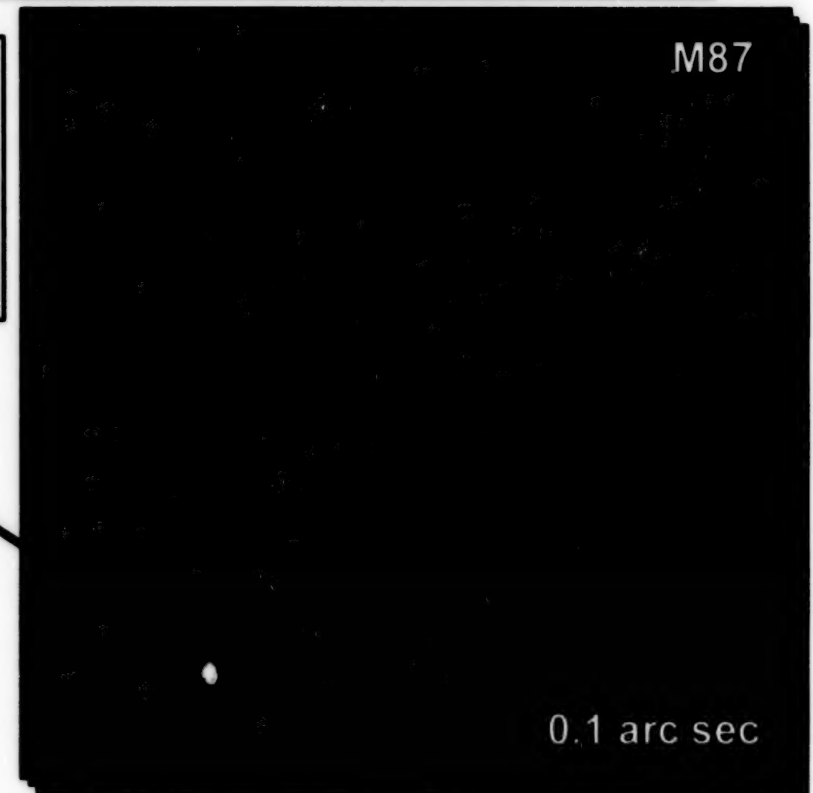




The Ultimate Goal!

Take direct image of a black hole event horizon

- Ultimate journey to visit a black hole
- Fundamental importance to physics
- Will capture the public imagination



X-ray interferometry is the best approach

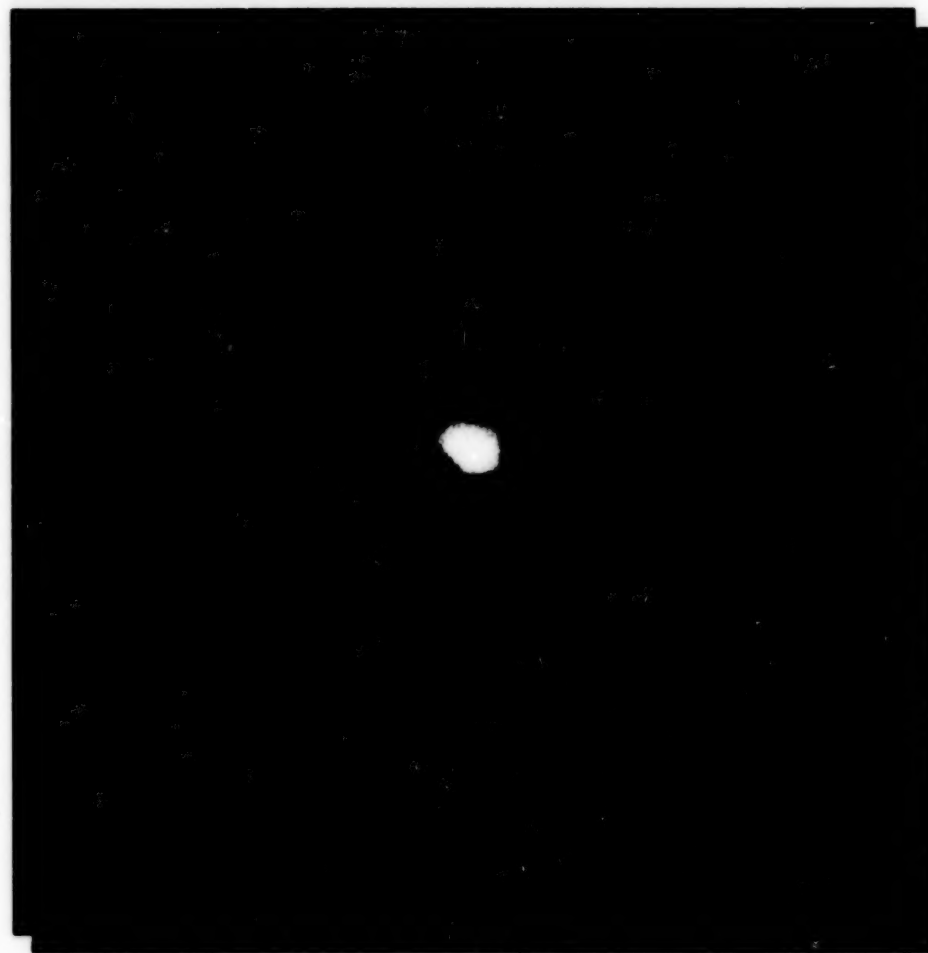
- Baseline of 20 m at 1 Å for 1 μ arc second
- Close to event horizon, energy is emitted in X-rays

Requires 0.1-1 μ arc second imaging



New Physics from Cosmic Catastrophes

- **Understand mechanisms by which Black Holes are born and grow**
- **Understand nature and origin of dark matter**
- **Verification of new particles: WIMPs, Axions, etc.**
- **Observational tests of string theory**
- **Critical tests of general relativity**





New Physics from Cosmic Catastrophes

What is Needed?

- Spectral/Imaging in IR, X-rays, gamma rays to study image and resolve ejecta in supernovae in nearby galaxies
- High sensitivity (1000x present capabilities) spectroscopy to study products of explosive nucleosynthesis in distant supernovae
- Multiwavelength transient observations with increasing capabilities to study gamma-rays bursts
- Increased emphasis on 3-D explosion codes
- Partnership with DOE labs



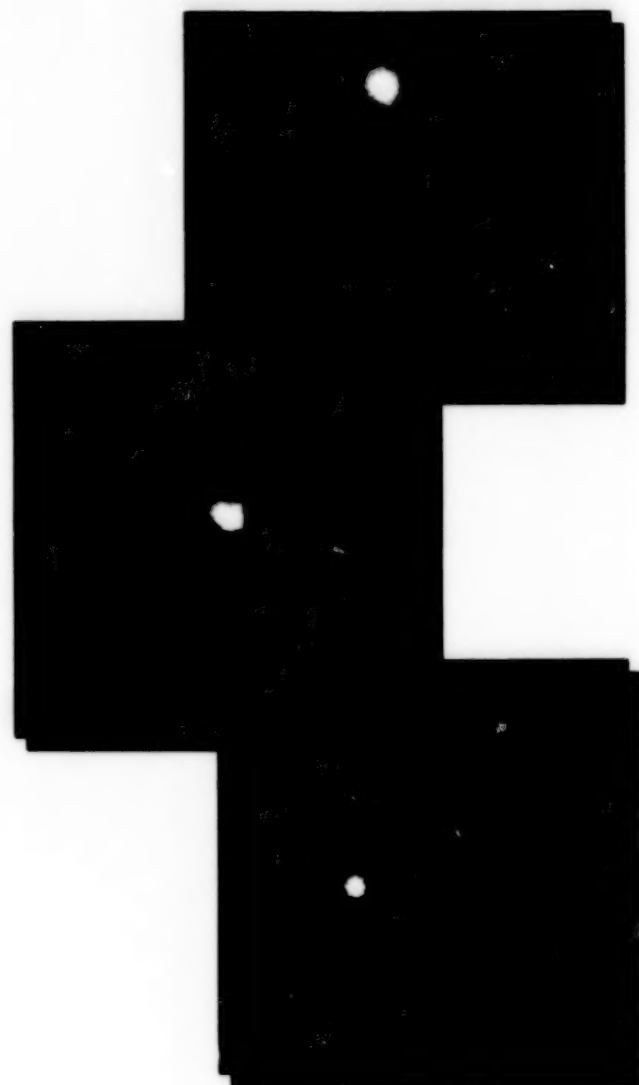


Gaps in Measurement Capabilities to Address Grand Challenges

- **Black Hole Images and Super-Astrometry**
- **X-ray, sub-millimeter, and radio super high angular resolution**
- **Micro- to nano-arcsecond resolution in X-ray and sub-millimeter**
 - SIM is the star tracker!
 - Need aggressive high resolution X-ray and sub-millimeter optics program
- **Very large Gamma Ray Telescopes**
 - Focusing is not possible
 - Requires much larger collectors
- **Detect the Big Bang**
 - Solar System-sized Gravitational Radiation Antennae



The Payoff



Voyage to the Beginning of Time

- Nature of energy, dark matter, the vacuum energy, and the ultimate fate of the Universe

Search for new physics

- Achieve Grand Unification

What's really going on!



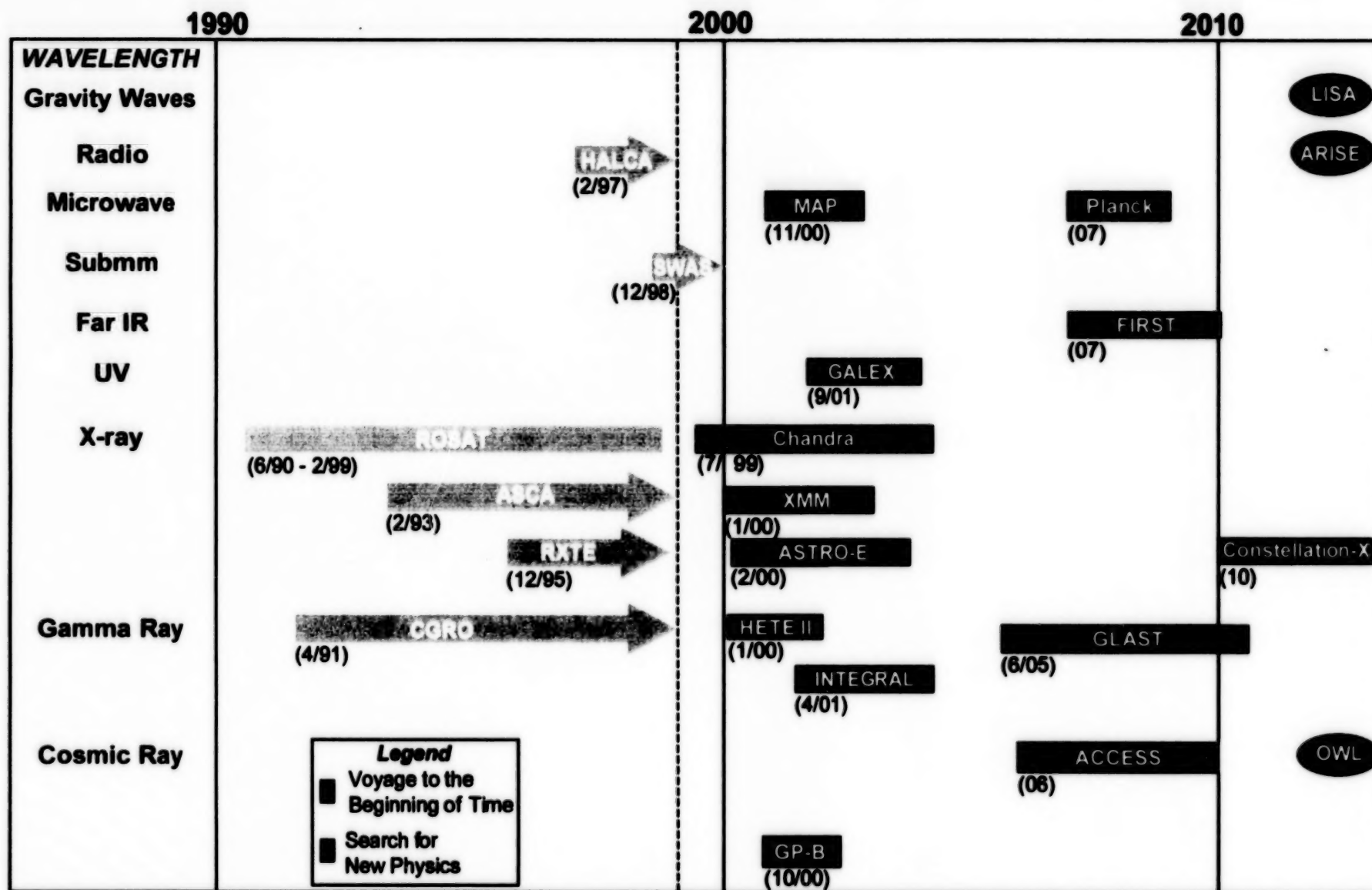
SEU Science Outcomes Metrics for FY99

Near term science milestones tied to OSS Strategic Plan, page 5:

- 3. Observe the evolution of galaxies and the intergalactic medium - The launch of AXAF opens a new capability for high angular resolution (0.25-0.5 arc second) imaging. By 30 September 1999, AXAF will record at least 100 x-ray images of our Milky Way galaxy and other galaxies at an angular resolution a factor 10 better than the prior Einstein Observatory.
- ✓ • 5. Test the theory of general relativity - By September 1999, advances will be made by RXTE and other space observatories in testing general relativity through x-ray observations of phenomena in the strong field regions within 1 to 10 Schwarzschild radii of black holes and neutron stars, 25,000 times closer to the event horizon than optical images permit.
- ✓ • 6. Identify the origin of gamma-ray bursts - By September 1999, the combination of space and ground telescopes (including CGRO, RXTE, HST, and AXAF) will determine at least 3 new distances or distance limits to gamma-ray bursts.
- 7. Study compact objects and investigate how disks and jets are formed around them - By September 1999, AXAF will have recorded data on at least 50 compact stellar objects, with a sensitivity 50 times higher than the Einstein Observatory.
- ✓ • 8. Study the formation and evolution of the chemical elements and how stars evolve and interact with the interstellar medium - By September 1999, SWAS will have investigated the energy balance in the interstellar medium by mapping key diagnostic spectral lines from star-forming clouds throughout the Milky Way.



Operational Timeframe for SEU Missions

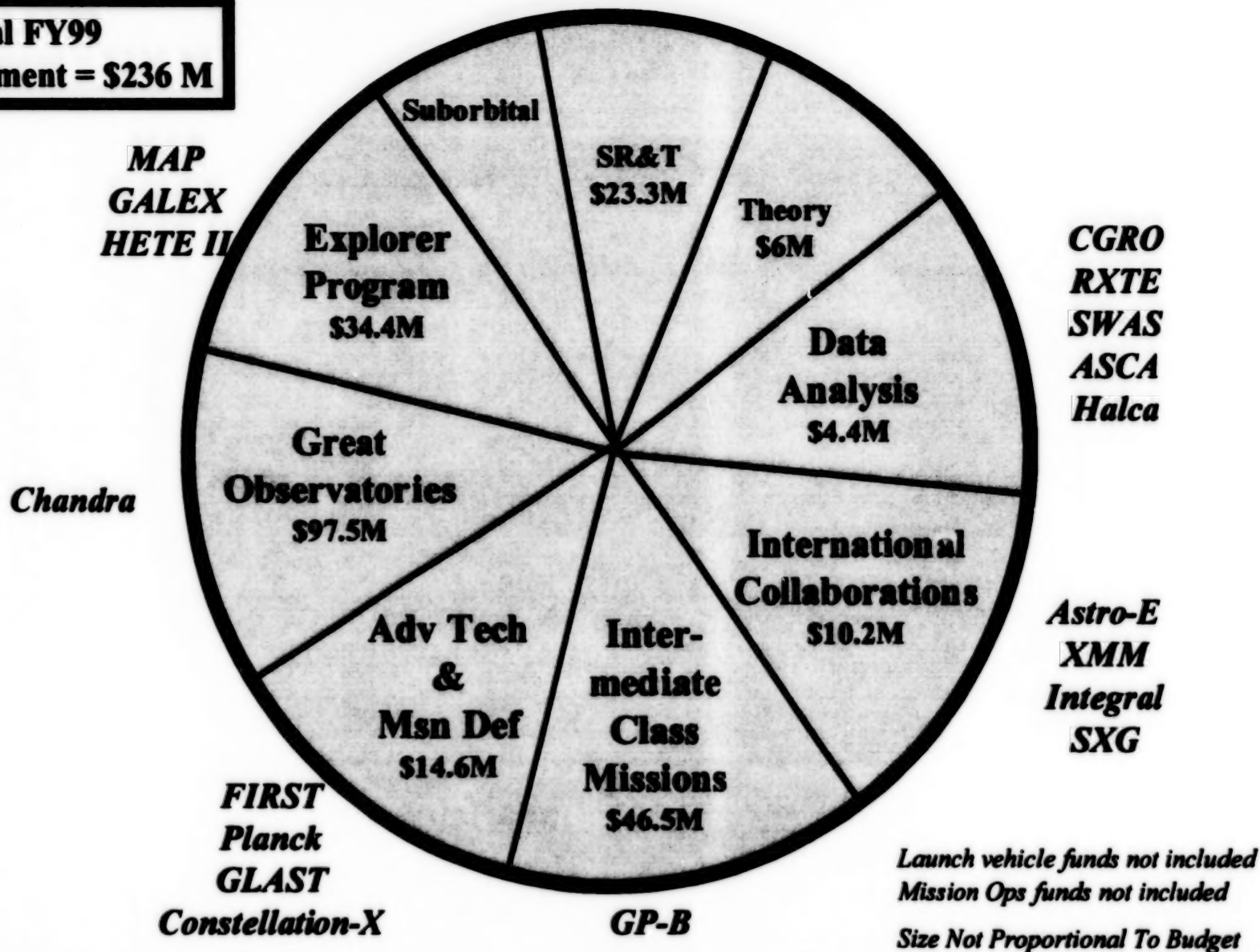




Structure and Evolution of the Universe

Elements of our Program

**Total FY99
SEU investment = \$236 M**





SEU Education Forum (@ SAO)

DEVELOPED HIGH-LEVERAGE OUTREACH OPPORTUNITIES:

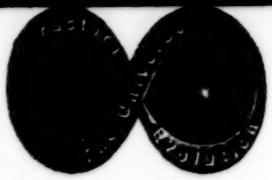
- **Created comprehensive strategy, with Association of Science and Technology Centers (ASTC), to enhance collaborations between science museums and space scientists.**
 - Granted three workshops with space scientists to be held at ASTC's 1999 annual meeting.
- **Co-produced planetarium show on SEU theme with Boston Museum of Science.**
 - Co-producing version to travel to other planetariums, with ancillary educational materials.
- **Led two workshops for teachers on the SEU theme at the 1999 National Science Teachers' Association meeting.**
 - Workshops included participation of three SEU missions: Chandra, RXTE, Space VLBI.
- **Hosted meeting with New York Times Newspapers => Exploring possibility of ongoing collaboration between SEU scientists and NY Times education programs.**
- **Continued to advise producers and writers of a three-part National Geographic Television special on the Universe, Life, and the Mind.**
- **Developing educational materials for NOVA's "Mapping the Universe" show.**

<http://cfa-www.harvard.edu/seuforum>



Education and Outreach at GSFC

- **SEU education & outreach activities are a service of the HEASARC (High Energy Astrophysics Science Archive Research Center)**
 - GSFC Education Products
 - > Astronomy Learning Center CD-ROM - Version 3
 - > Activity Booklets & Posters: "Anatomy of a Black Hole"
 - > Support @ Conventions: workshops; exhibit booths; materials
- **SEU Websites**
 - <http://universe.gsfc.nasa.gov/>
 - > SEU Theme site for NASA and general public use
 - <http://imagine.gsfc.nasa.gov/>
 - > Imagine the Universe! educational site for grades 9-12
 - <http://starchild.gsfc.nasa.gov/>
 - > a learning center for young astronomers (4-8)
- **Getting the Word Out**
 - "Cosmic Horizons" - brochure for general consumption
 - "Journey to a Black Hole" video



BOOMERANG:
Sub-Orbital Precursor to the *Planck* Surveyor
(Planck Surveyor on a Rope)

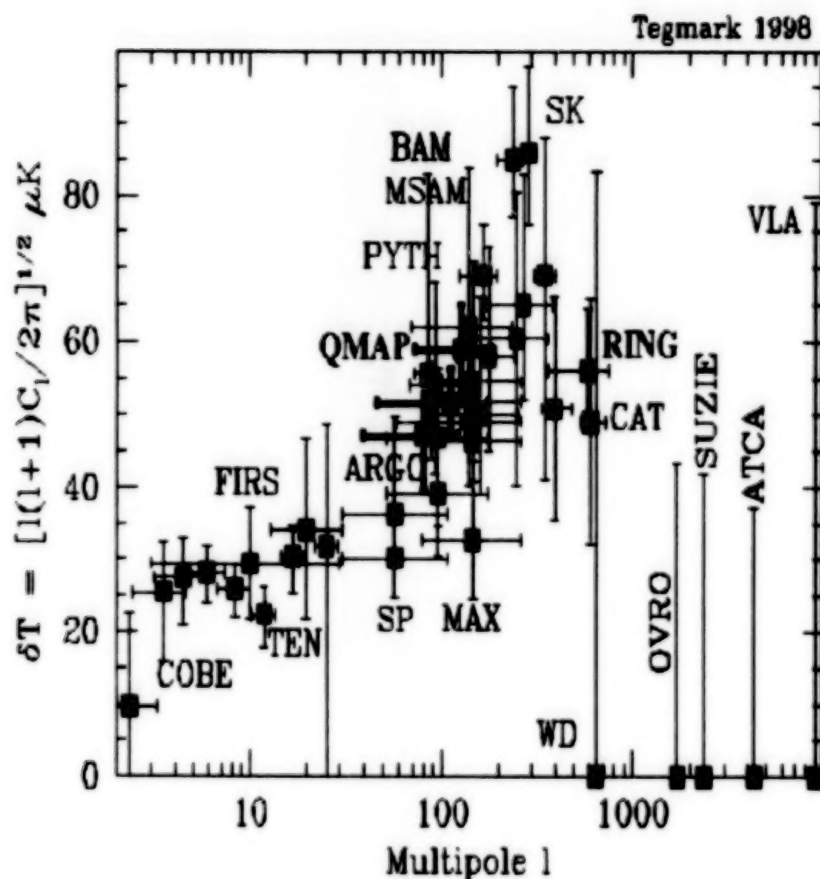
Jamie Bock
Jet Propulsion Laboratory

<http://www.physics.ucsb.edu/~boomerang/>

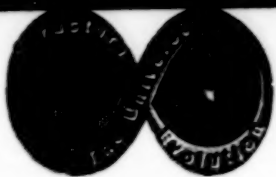


***BOOMERANG* Science Goal:**

Resolve the spatial structure in the CMB



- **Size and amplitude of structures not resolved by COBE should yield accurate measurements of most cosmological parameters (Ω , Ω_m , Ω_Λ , H_0 , ...)**
- **Need both high angular resolution and sensitivity to detect these features**



The Ideal Sub-Orbital Environment:

Antarctic Long Duration Ballooning (LDB)

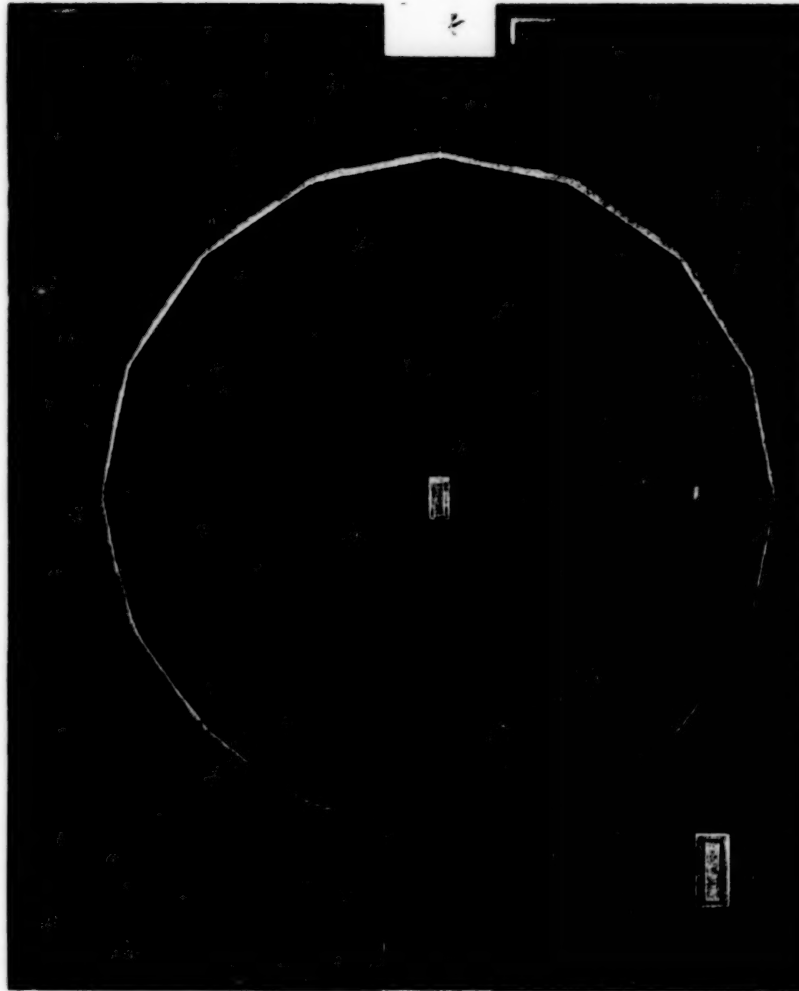


- **10+ days at 120,000 ft**
- **Continuous TDRSS link**
- **Orbit-like Environment**
 - Negligible atmospheric emission
 - High cosmic ray flux
 - High temperature gradients
 - Challenging EMI/RFI
 - Challenging Launch Ops



Sub-Orbital Enables Orbital:

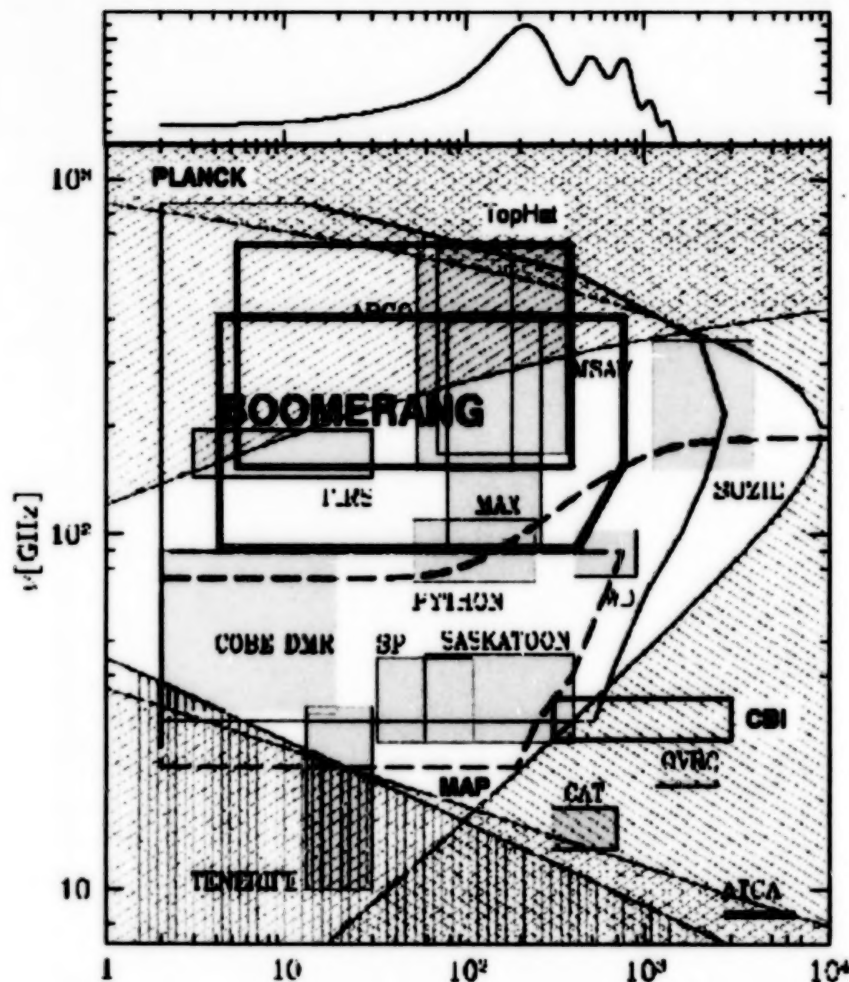
Technology



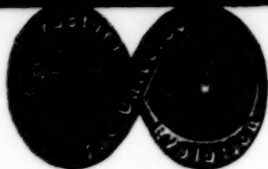
- **“Spider-web” bolometer architecture originally motivated by Antarctic LDB observations (low cosmic ray cross-section)**
- **LDB-driven technology enabled the Planck Surveyor (and secured U.S. role in this mission)**
- **Arrays of “spider-web” detectors now developed at JPL are under study for FIRST**

Sub-Orbital Enables Orbital:

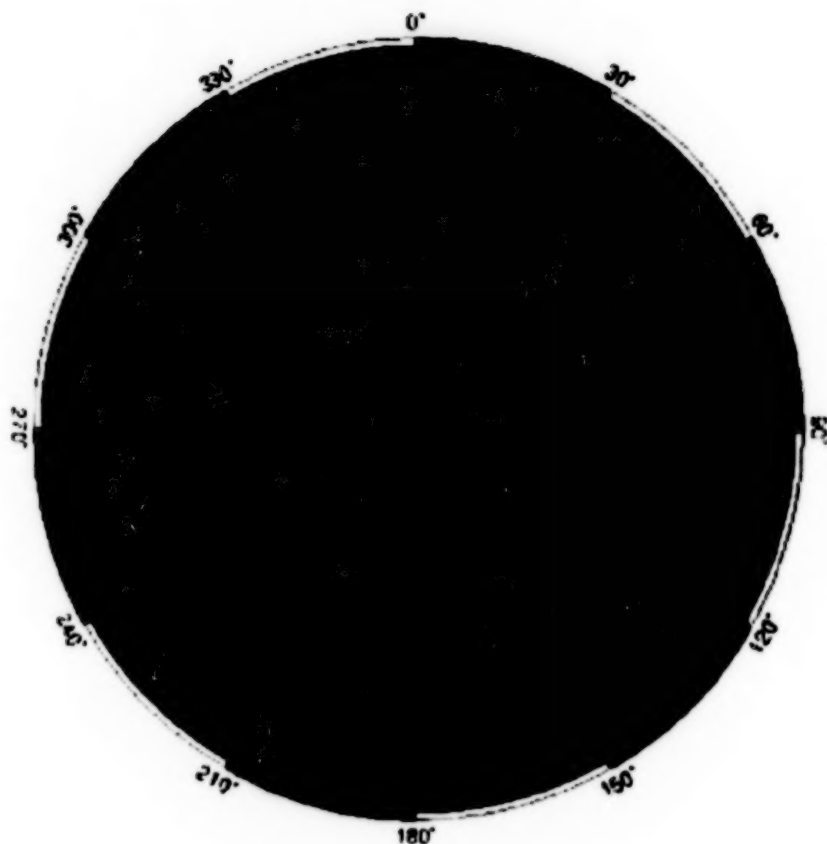
Science



- **BOOMERANG (1999) :**
90, 150, 220, 440 GHz
10' resolution
- **Complements MAP (2000):**
20, 30, 45, 60 and 90 GHz
12' resolution
- **Enables Planck (2007):**
30, 45, 60, 100, 150, 220, 350,
550, 850 GHz
5' resolution



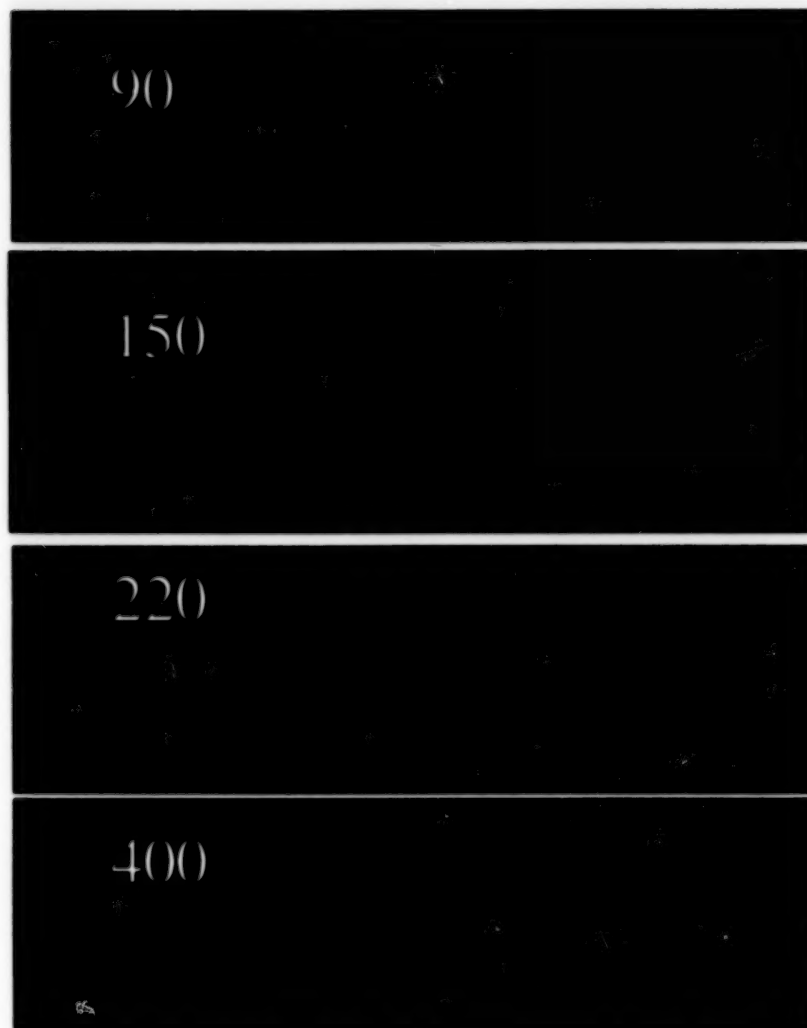
BOOMERANG: 98/99 LDB Flight



- **10.5 days of continuous and flawless observation**
- **Instantaneous sensitivity:**
 - ~ 100x COBE
 - (1 LDB day = 20 COBE years!)
- **Angular resolution:**
 - ~40x COBE
- **TDRSS link allowed real-time analysis and control**
- **Payload recovered intact 50 km from launch site**



BOOMERANG Preliminary Results I:



- **First high resolution maps of mm-wave Galactic emission:**

- confirm "window" in galactic emission at 90, 150 GHz, excellent correlation with IRAS
- constrain effects of dust contamination on *MAP*, *Planck Surveyor*



BOOMERANG Preliminary Results II:

Figure: First high S/N, resolved
images of CMB anisotropies

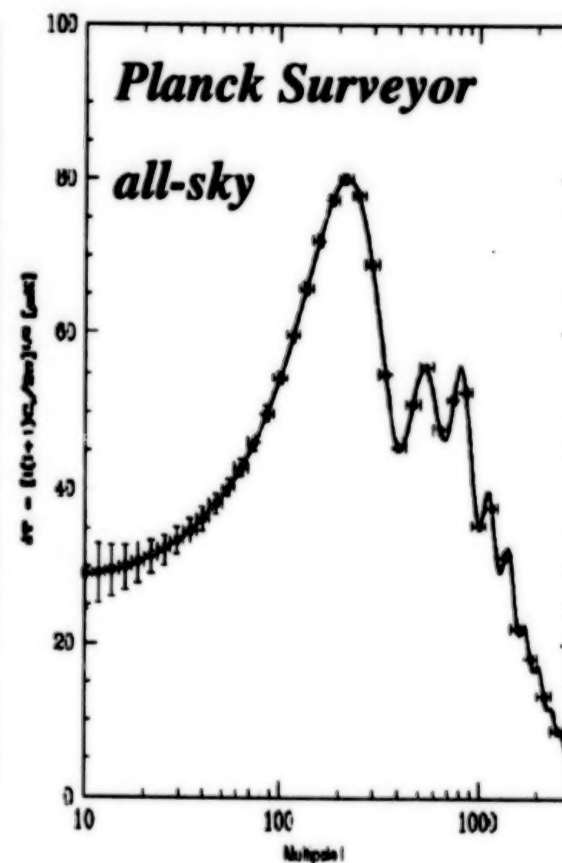
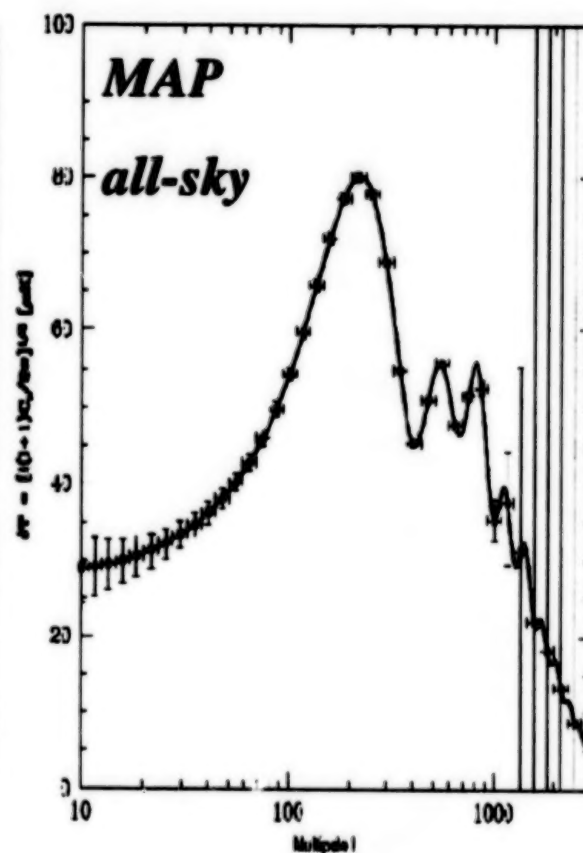
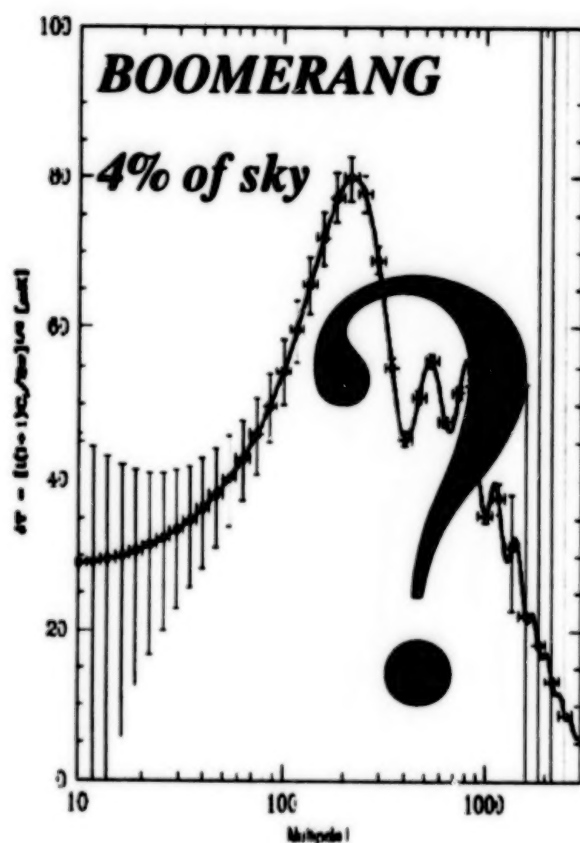
(proprietary image - will be
shown on May 18, 1999)

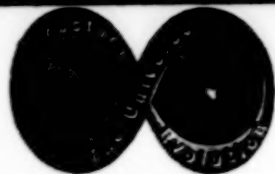
- **Sub-Kelvin
"Spider Web"
bolometers +
LDB = first
high signal-to-
noise ratio,
resolved
images of CMB
structure**



BOOMERANG, MAP and Planck:

BOOMERANG achieved both high angular resolution and high sensitivity but is ultimately vulnerable to systematic effects that are vastly smaller for orbital missions. The ultimate precision with which BOOMERANG will have determined the power spectrum is not yet known. Ultimate confirmation of any result will await data from MAP, which will have exquisite control of systematics by virtue of both design and environment.





Cost of BOOMERANG

- **Cost shared ~ 50/50 between U.S. (P.I. Lange) and Italy (P.I. deBernardis)**
- **US cost shared ~ 50/50 between NASA/NSF**
- **Total NASA support < \$200k/yr x 6 years**



The Next Step:

Probing Inflation via CMB Polarization

- Requires μK sensitivity on degree angular scales, beyond capability of MAP
- Flight-proven *BOOMERANG* payload recovered intact
- Modified focal plane will provide CMB polarimetry
- Re-flight in 12/00 (contemporary with MAP)
- $\sim 2 \mu\text{K}/\text{pixel}$ on $\sim 10^3$ pixels
 - (cf. *MAP* $\sim 35 \mu\text{K}/\text{pixel}$ on $\sim 10^6$ pixels)
- Technical and scientific precursor to post-*Planck* CMB polarimeter

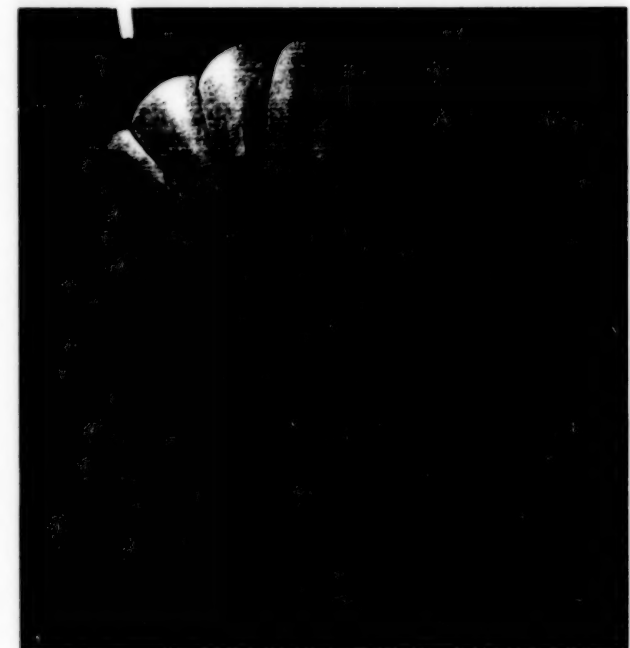


NASA Balloon Program

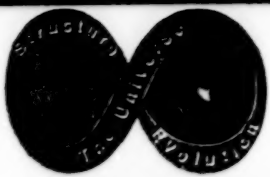
- **Long Duration Balloon (LDB) flights of 10 to 20 days**
 - Operational (local summer only)
 - Antarctica or Fairbanks, AL
 - Conventional balloon at high latitude
- **Ultra Long Duration Balloon (ULDB) demo 60 to 100 days**
 - Planned for December 2001 (local summer only)
 - Christchurch, NZ
 - New super-pressure balloon
- **Olympus Balloon >100 days**
 - Advance planning stage
 - Any time, any latitude (with latitude control)



ULDB Trajectory Simulation



ULDB Hangar Test



State of the Universe 1999

SEU Operating Missions
&
International Collaborations

Richard Mushotzky

Goddard Space Flight Center

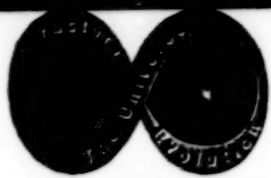


Uniqueness of these Missions

Most of these missions either are the first opportunity to perform this type of science or the first large scale follow-up to successful pioneering experiments

Operating Missions

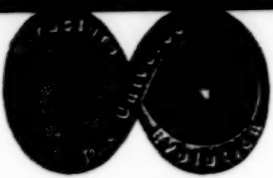
- **HALCA — First space VLBI**
- **SWAS — First submillimeter space spectroscopy**
- **ASCA — First spatially resolved X-ray spectroscopy**
- **Rossi XTE — First mission devoted to fast timing studies**
- **Compton GRO — First Great Observatory for Gamma Rays**
 - First sky survey at 500–5000 keV (COMPTEL)
 - First follow-on to $E > 50$ MeV sky survey (EGRET)
 - First sensitive experiment in 100–500 keV band (OSSE)
 - Most sensitive gamma ray burst monitor (BATSE)



Uniqueness of these Missions

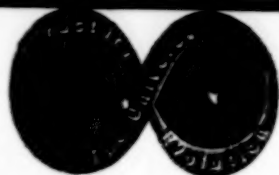
International Collaborations being readied for launch

- **XMM is the first large collecting area X-ray telescope**
- **Astro-E is the first flight of the X-ray calorimeter**
 - Exciting new technology
- **INTEGRAL is the follow-on mission to OSSE and COMPTEL**

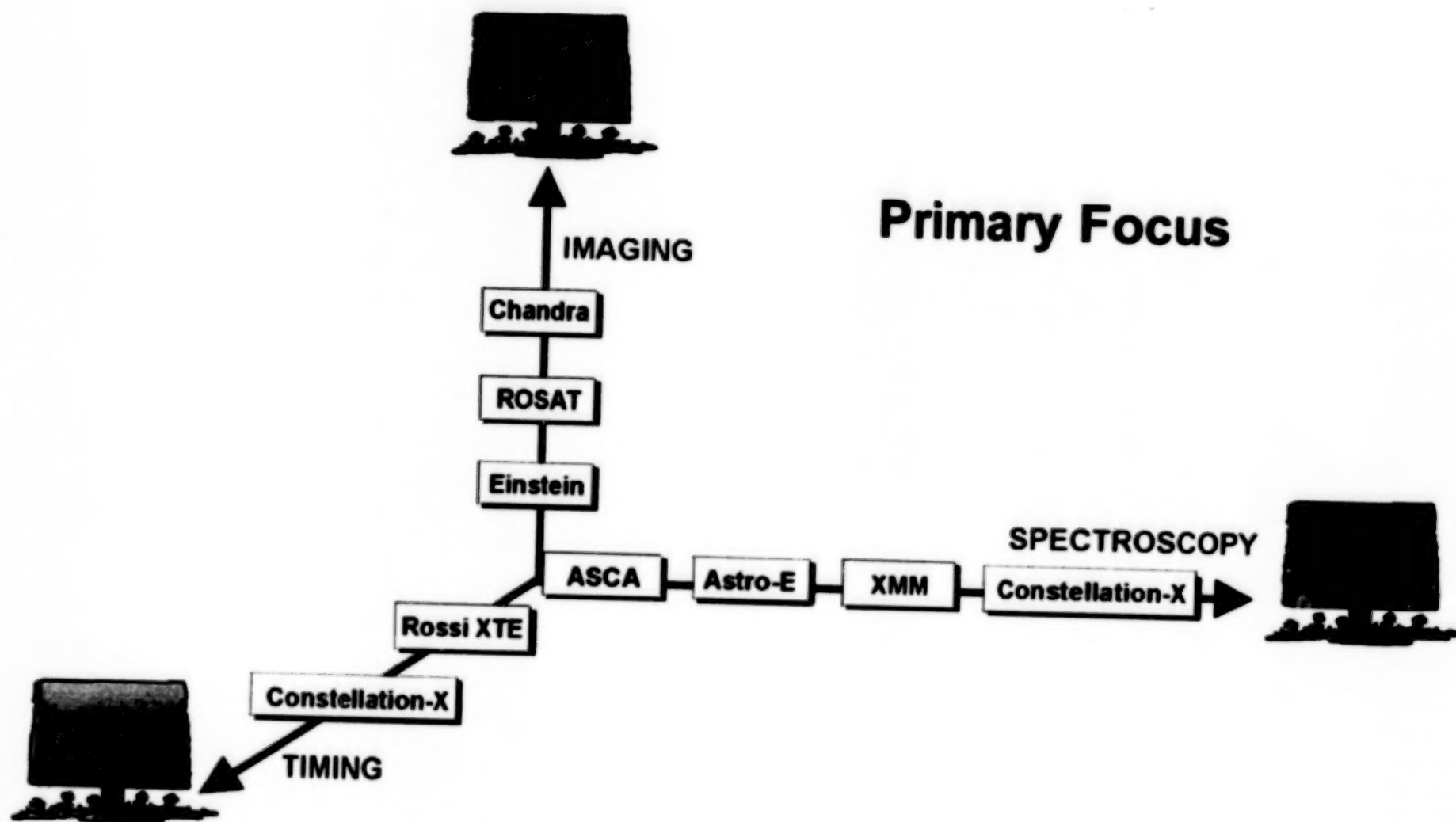


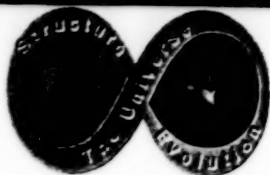
Uniqueness of these Missions

- **All of the science of these missions requires space observations**
 - Gamma ray, X-ray, submillimeter science cannot be done from the ground
 - The long baseline for space VLBI is not possible on the Earth
- **The level of sensitivity in these fields, which are in their growth phase, has improved by orders of magnitude in the last 20 years but still trails space and ground based optical telescopes**
- **Most of the phenomena studied by these experiments cannot be done in any other way**

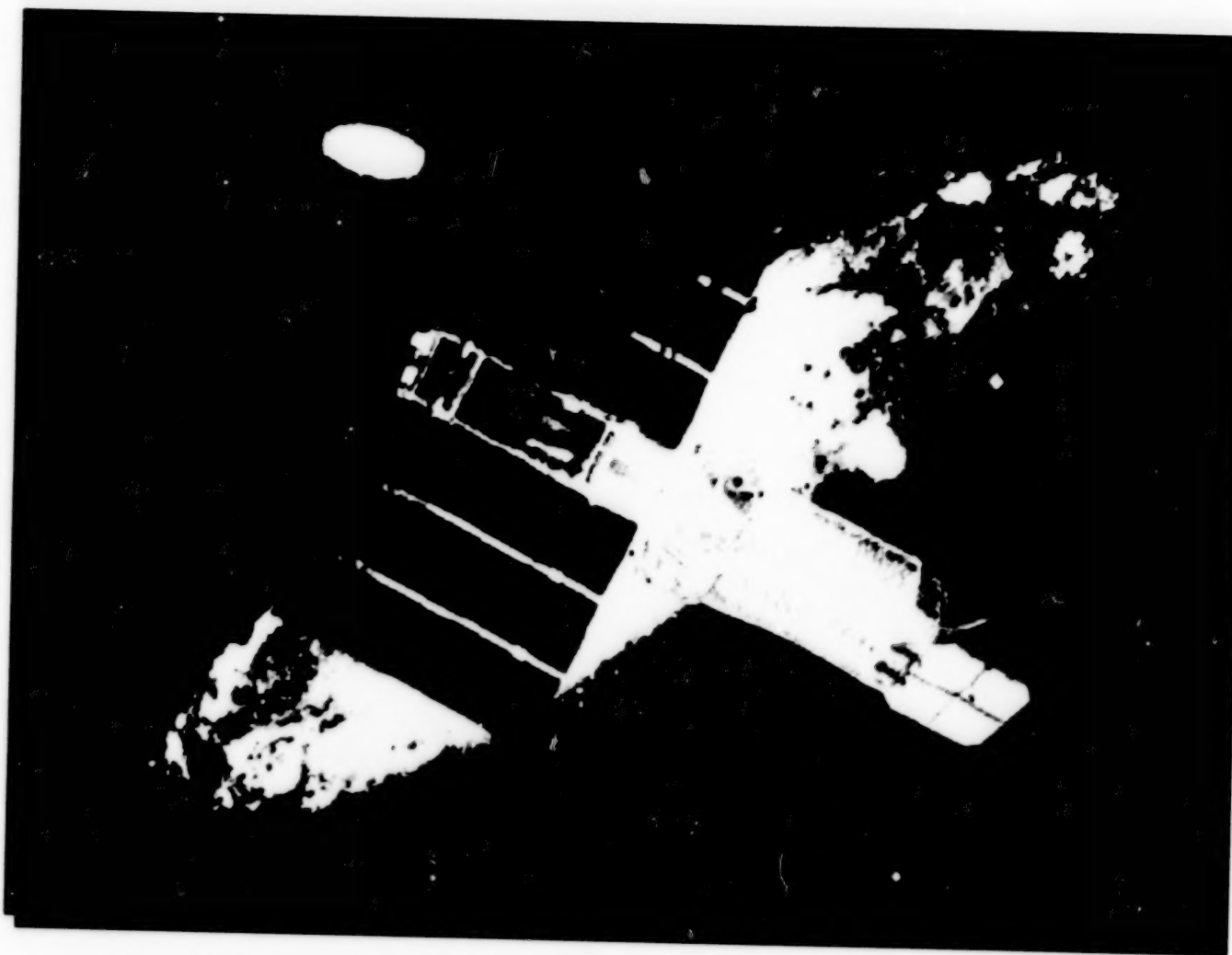


X-ray Missions





ASCA



<http://heasarc.gsfc.nasa.gov/docs/asca/ascagof.html>



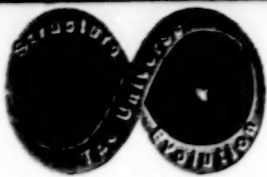
ASCA

- **Japanese-US Joint program**
 - U.S. provided X-ray telescopes and CCD cameras
 - Japan provided gas detectors, spacecraft, and mission operations
 - Software is joint effort
- **ASCA was the first X-ray imaging spectroscopy satellite**
 - Pathfinder for Chandra, XMM, and Astro-E
 - First mission to use X-ray imaging CCDs (M.I.T.) and lightweight, large collecting area X-ray optics (GSFC)
- **ASCA was ~100 times more sensitive in the medium 2–10 keV X-ray band than any previous mission (HEAO-1, EXOSAT, Ginga)**



ASCA

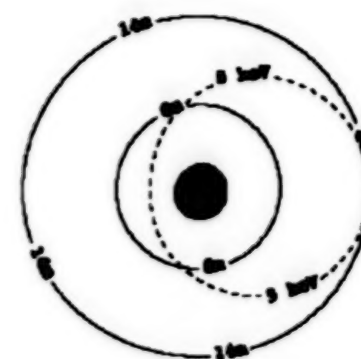
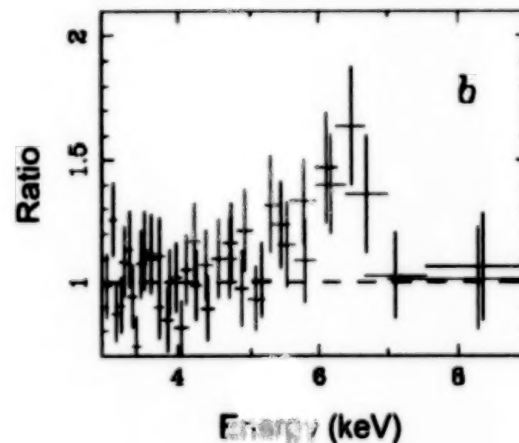
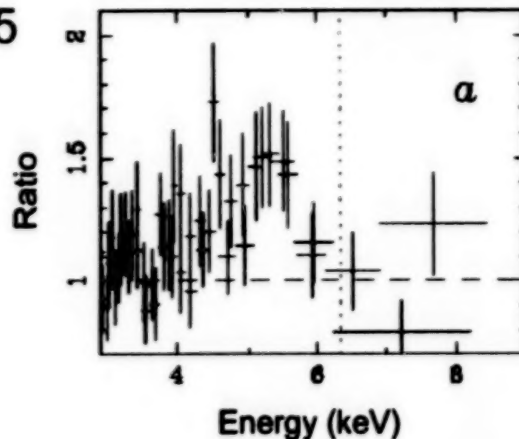
- **Prime science has been imaging X-ray spectroscopy of a wide variety of objects**
 - Stars
 - X-ray binaries
 - Supernova remnants
 - Active galaxies and quasars
 - Galaxies
 - Groups and clusters of galaxies
- **The ASCA extended mission has resulted in large samples of objects in a very useful active data archive**
- **At the present time ASCA is working well**
 - One of the instruments has somewhat degraded performance (CCD detector is suffering from radiation damage)
 - Predicted reentry is early-mid 2000
 - "Final" AO was late last year



ASCA Scientific Results

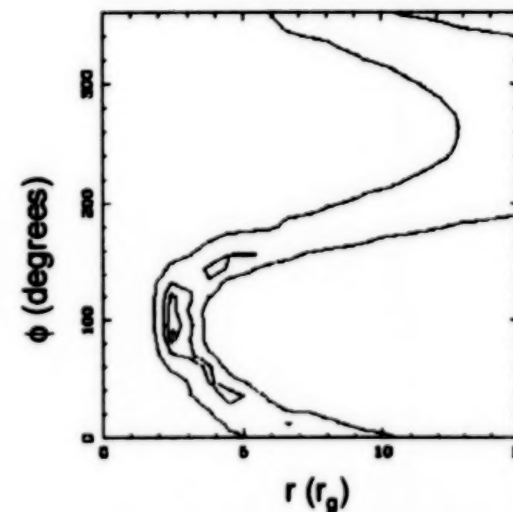
MCG-6-30-15

Change in line energy with time gives geometrical information



$i = 30, a = 0.998$

First map of the regions close to a black hole

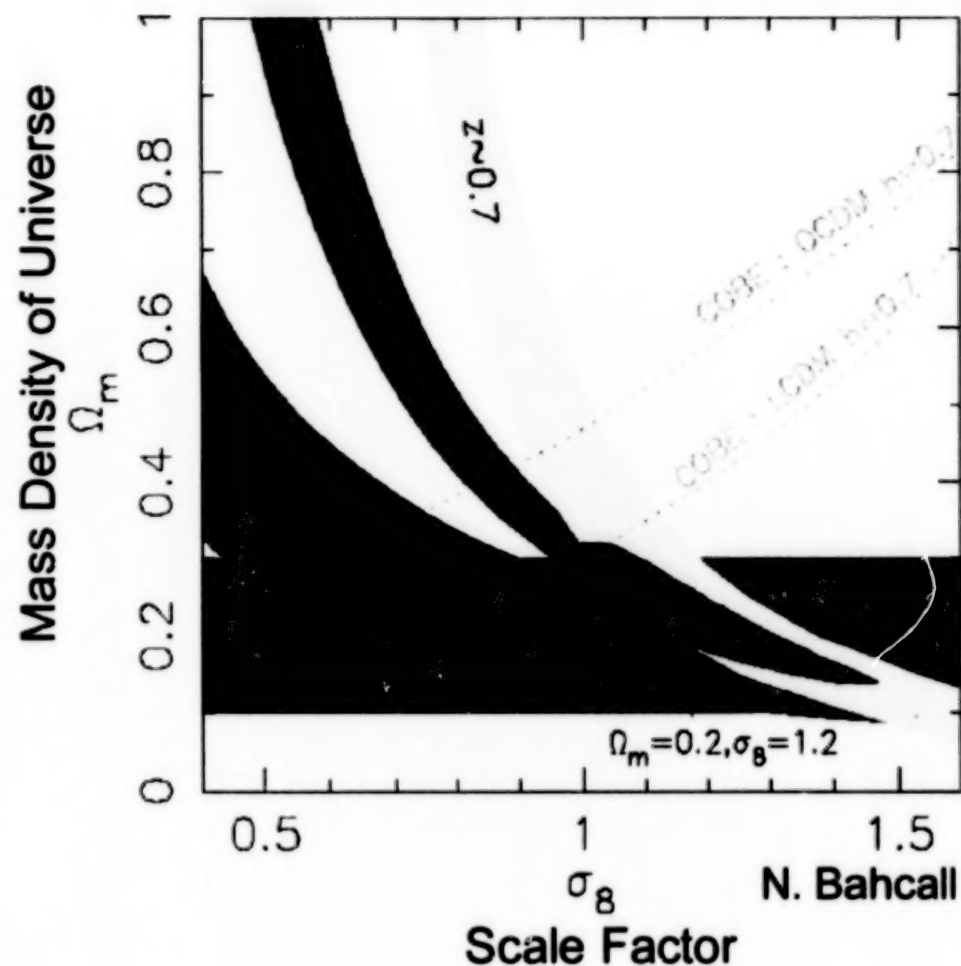


Iwasawa et al., 1999

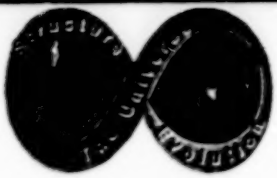
- **Discovery of relativistically broadened Fe K lines from active galaxies**
 - First spectral signature to be discovered from just outside of event horizon of supermassive black hole



ASCA Scientific Results

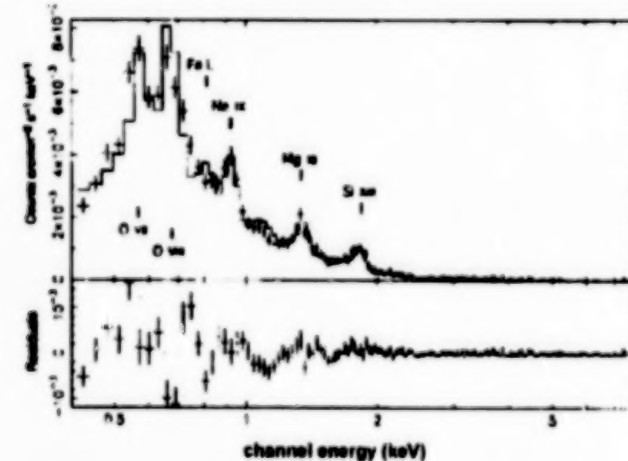
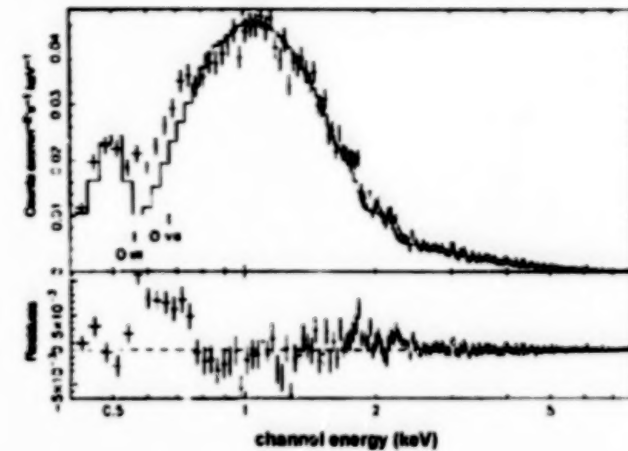


- **First accurate measurement of**
 - Mass and mass profiles of clusters and groups of galaxies
 - Determination of the relative amounts of baryonic and dark matter
- **Strongest indication of low Ω Universe and that much of the visible baryonic matter in the Universe resides in groups**



ASCA Scientific Results

Discovery of the origin of cosmic rays

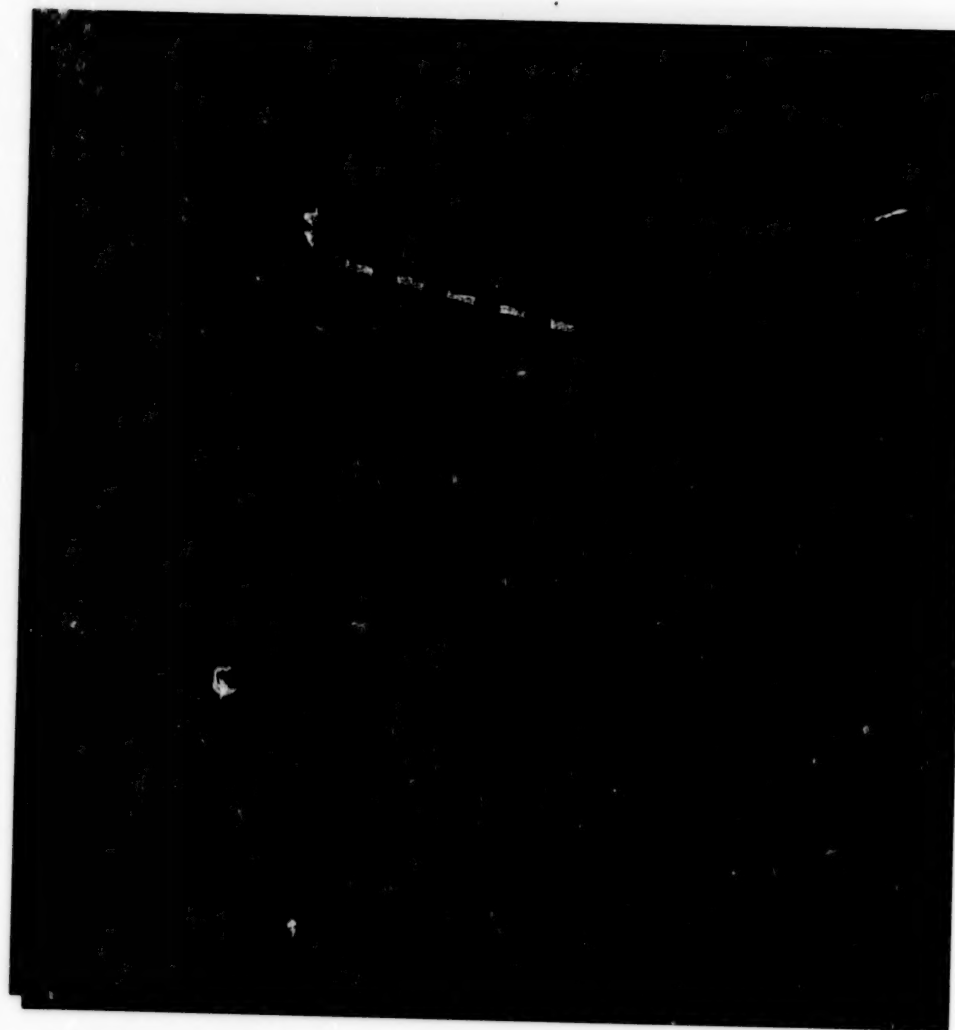


- **ASCA spectral of several supernova remnants have shown that they are producing synchrotron X-rays from TeV electrons**
 - Implies direct acceleration of cosmic rays

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Rossi X-ray Timing Explorer

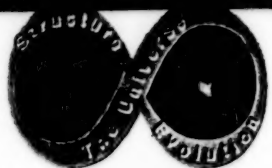


http://heasarc.gsfc.nasa.gov/docs/xte/xte_1st.html



Rossi X-ray Timing Explorer

- **RXTE is a U.S. program with no international collaboration**
- **The three instruments are**
 - All-Sky X-ray monitor (M.I.T.)
 - 8,000 cm² large area proportional counter (PCA 2–60 keV) (GSFC)
 - High energy (20–200 keV) scintillator — HEXTE (UCSD)
- **All sky monitor and proportional counter are both state-of-the-art instruments which are much more sensitive than their predecessors**
 - “New window” on micro- to millisecond timing
 - Orbit period of inner accretion disk surrounding stellar mass black hole and neutron stars
 - Ultimate spin period of neutron stars
- **RXTE is at present working well**
 - Possible long term degradation of some of the PCA counters but controlled by “resting” individual modules



Rossi X-ray Timing Explorer

- **Mission operations are very smooth and a very large number of target of opportunity observations are being performed**
- **There is no presently approved or proposed follow-on to RXTE PCA and its science remains unique until Constellation-X**
- **There are successors to the ASM and HEXTE experiments**
 - Successor to the ASM may be the Japanese experiment on the International Space Station
 - HEXTE successors are
 - > Hard X-ray experiment on Astro-E
 - > IBIS on INTEGRAL



Rossi X-ray Timing Explorer

- **RXTE has extended the frontiers of research in X-ray binaries using**
 - Large collecting area
 - State-of-the-art data system
 - High telemetry rate
 - Low background
- **Discovery of kilohertz variability in neutron stars and black holes**
- **These phenomena occur very close to the Schwarzschild radius and are direct probes of accretion and the physics in strong gravitational field**

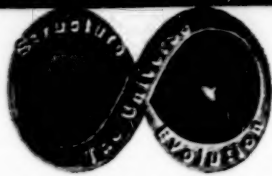


Rossi X-ray Timing Explorer

The RXTE data address fundamental physics questions such as

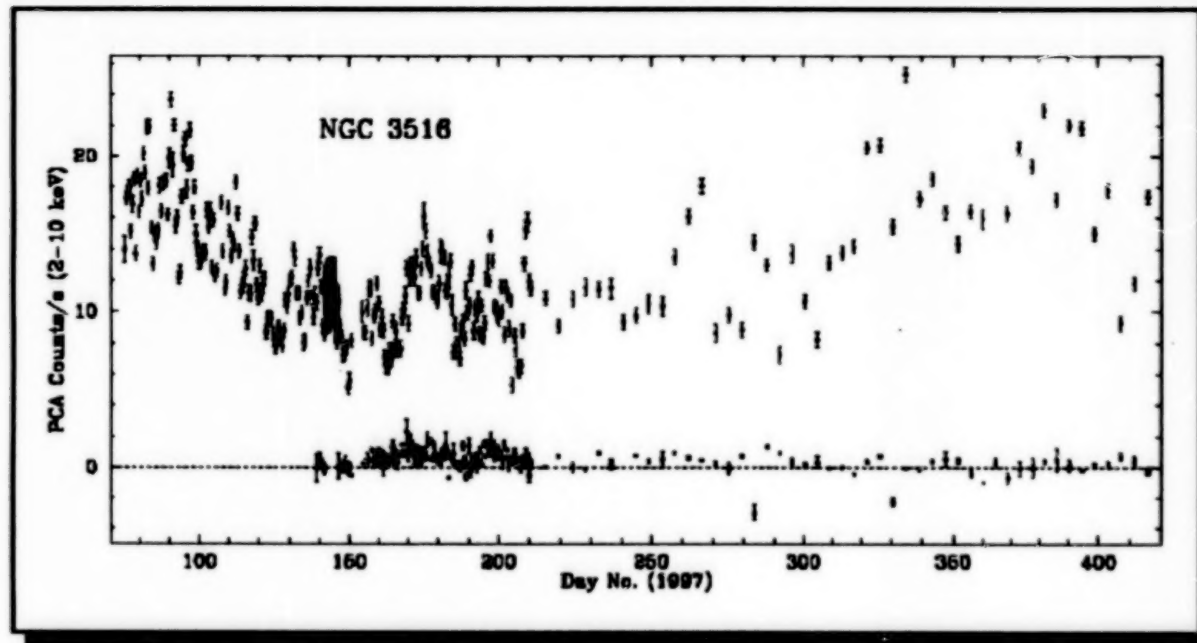


- **Equation of state of neutron stars**
- **Possible confirmation of the existence of an innermost stable orbit as predicted by General Relativity**
- **Existence of magnetars**
 - Neutron stars with $> 10^{14}$ G magnetic fields



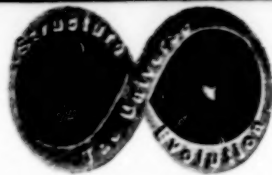
Rossi X-ray Timing Explorer

- Another major science goal has been the study of time variability and spectra of active galactic nuclei

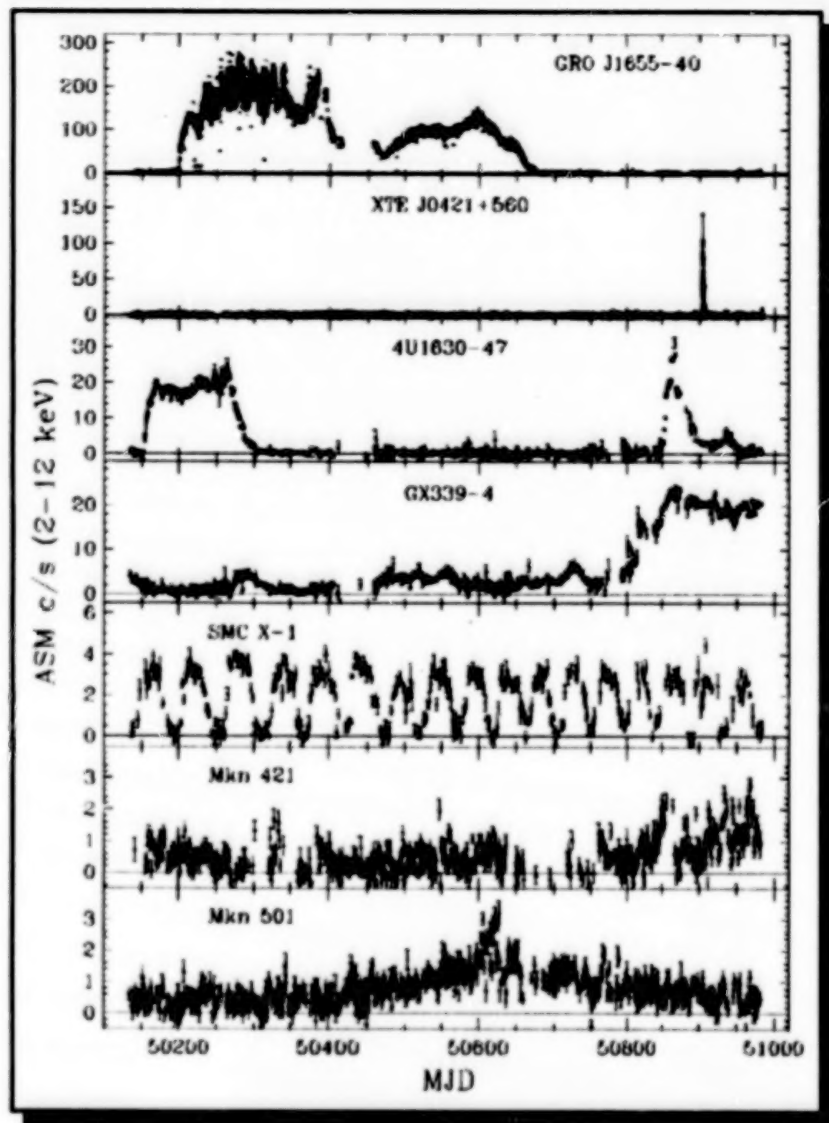


- Variability from hours to years
- These objects are ~ 500 times fainter than the X-ray binaries

- Data analysis complex and first results are just being published now
- RXTE has shown that variability scales with mass of black hole



Rossi X-ray Timing Explorer



- **The All Sky Monitor has provided the first long term record of variability in the X-ray sky since the late 1970s**
 - Has discovered numerous X-ray transients which have been followed up by pointed observations
- **RXTE also benefits from having an extremely flexible missions operations concept and spacecraft**
 - Has conducted over 500 target of opportunity observations

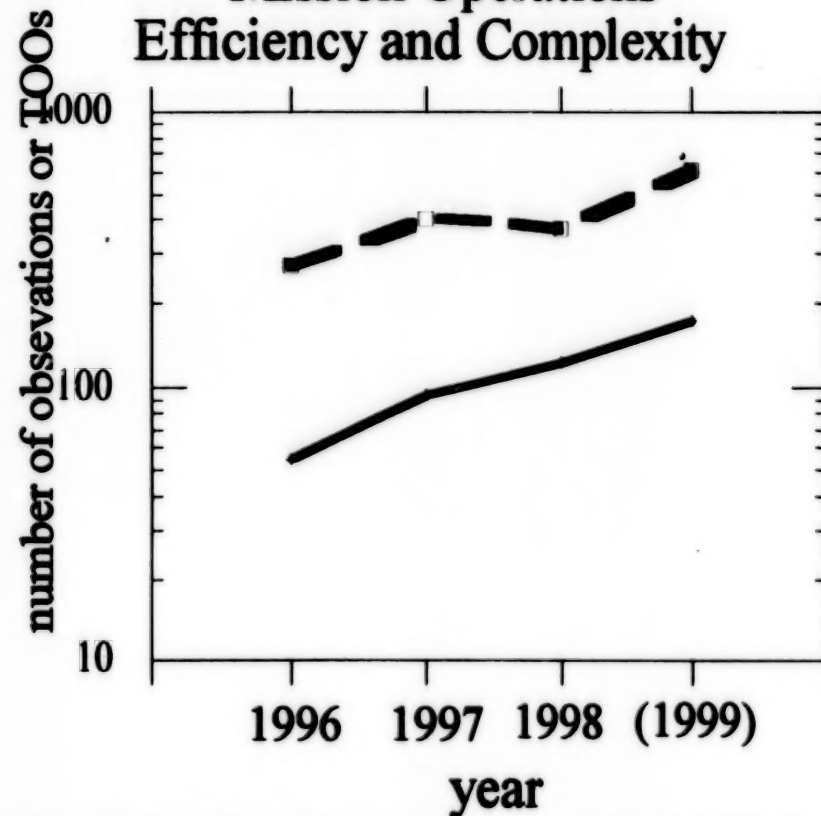


RXTE Mission Operations

Mission operations continue to increase in number of observations per year and number of targets of opportunity

- **RXTE is the most flexible astronomical spacecraft now flying**
 - Performs large number of targets of opportunity observations
 - Performs large and increasing number of observations per year
 - Provides a large number of guest observers with data

Continual Increase in XTE Mission Operations Efficiency and Complexity



— XTE TOOs
- - XTE total observations/yr



Compton Gamma Ray Observatory (CGRO)



<http://coss.c.gsfc.nasa.gov/>



CGRO - Mission Status

- **EGRET: Three to four months of gas remaining**
 - To be used for TOO observations in next year
- **OSSE and BATSE: 100%**
- **COMPTEL: 95%**
- **After last reboost, higher orbit gives mission life through 2005**
 - Funded through 2002
- **Senior review had solar science for the next solar maximum as prime science goal of extended mission (OSSE, EGRET, COMPTEL)**
- **BATSE still unique for gamma ray bursts**
- **Strong recommendation for continued operation of all instruments**
- **Mission operations costs severely reduced**
 - Hours 9 AM - 5 PM, 5 days/week
- **More cost cuts planned next year**



CGRO Recent Accomplishments

Where are the missing supernovae?

There are only six “historical” supernovae

Great Zimbabwe Supernova of 1248

- **Age ~ 750 years**
- **Distance ~ 150 pc**

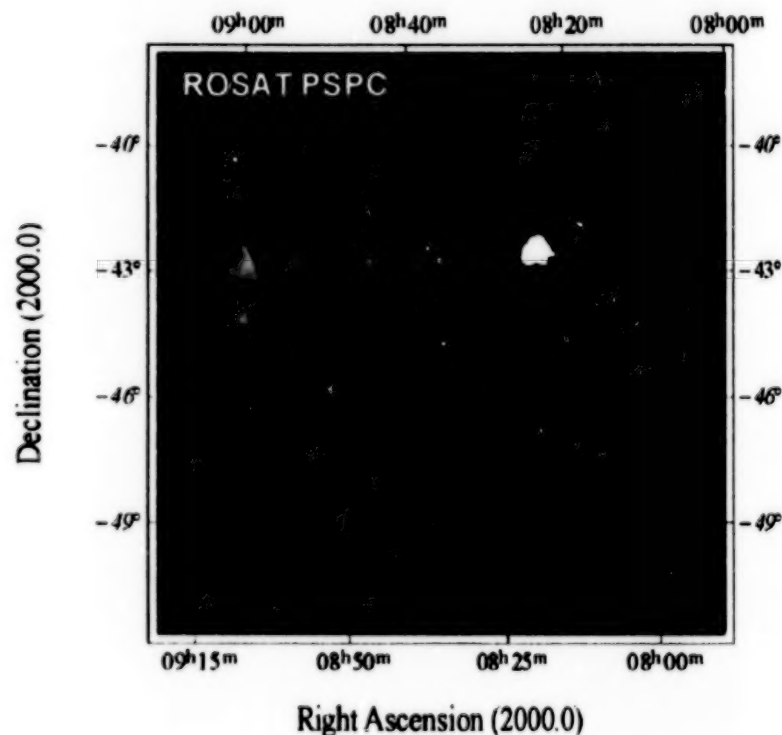
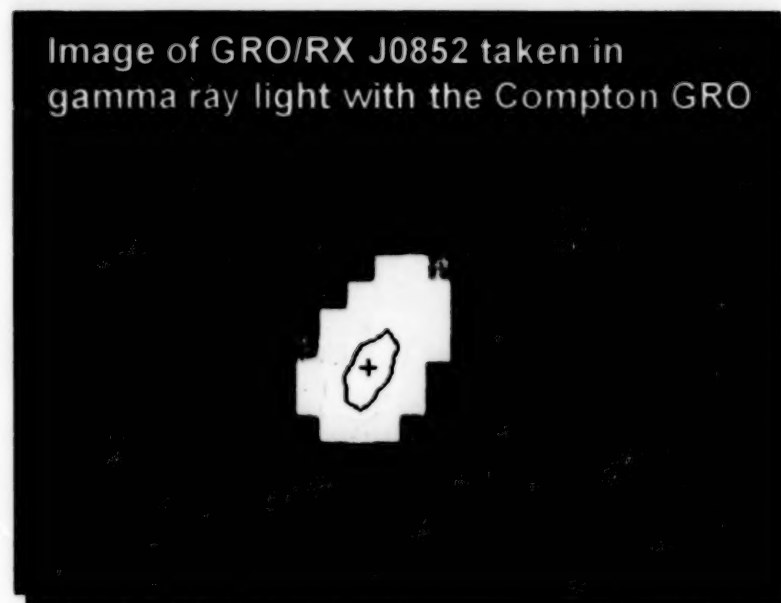


Image of GRO/RX J0852 taken in gamma ray light with the Compton GRO

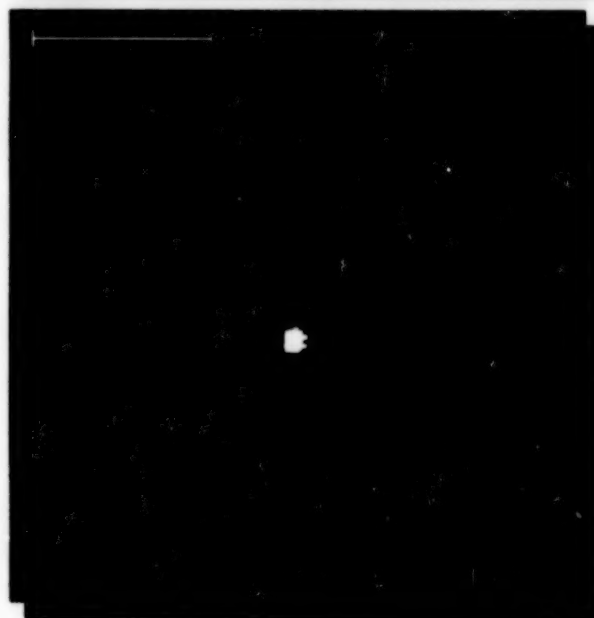
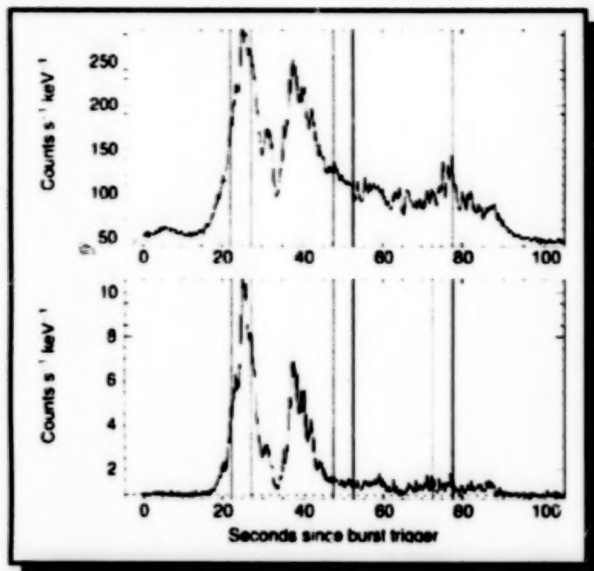


- **Event in southern hemisphere**
- **Found in light of radioactive Ti^{44}**
- **Confirmed by ROSAT image**

Must have been the brightest historical supernova



CGRO Recent Accomplishments



CP8 18

Prompt Optical Flash Detected From Gamma Ray Burst!

- **First time GRB was observed in the optical band while the burst was still bursting!**
- **ROTSE slewed to position provided by BATSE**
 - Detected the counterpart at 22 seconds after signal at 11.8 mag and brightening
- **In gamma rays, burst is in brightest 0.5% of nearly 3000 recorded by BATSE!**
- **In visual, “afterglow” emission is brightest seen to date by several magnitudes**
- **Redshift places it at $z = 1.6$, 4.5 Gpc**
- **If emission is released isotropically, total energy release is $\sim 10^{54}$ ergs — far greater than that any other known event except for Big Bang itself!**

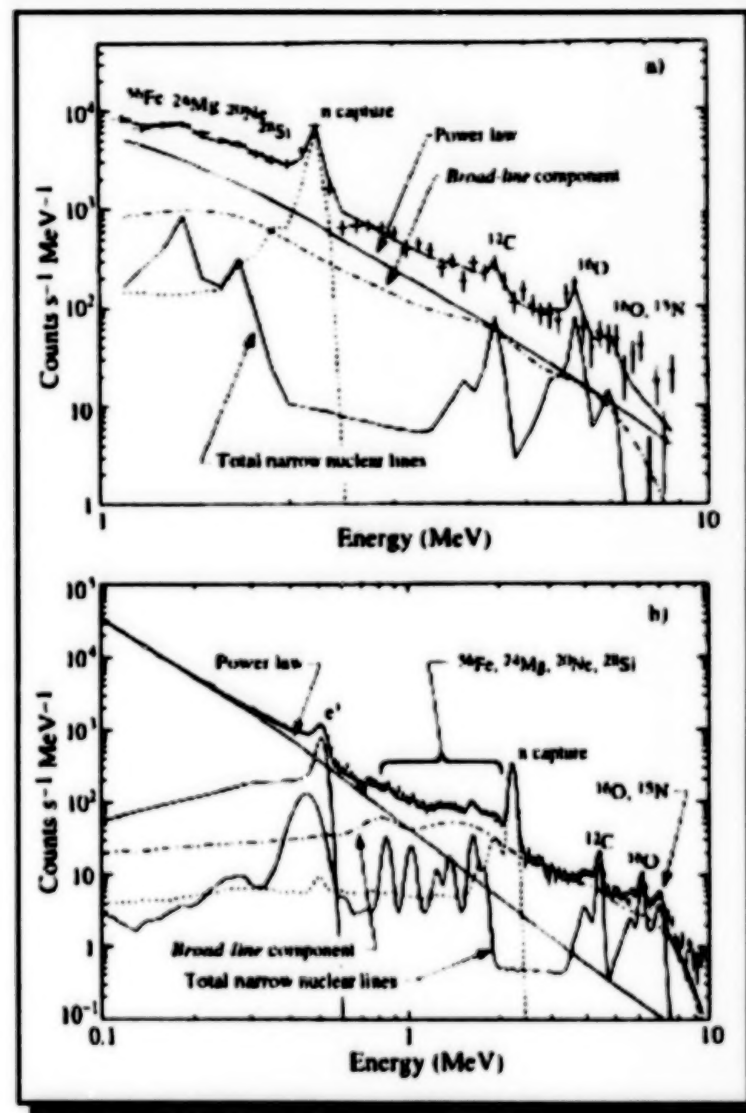
Operating Missions



CGRO Recent Accomplishments

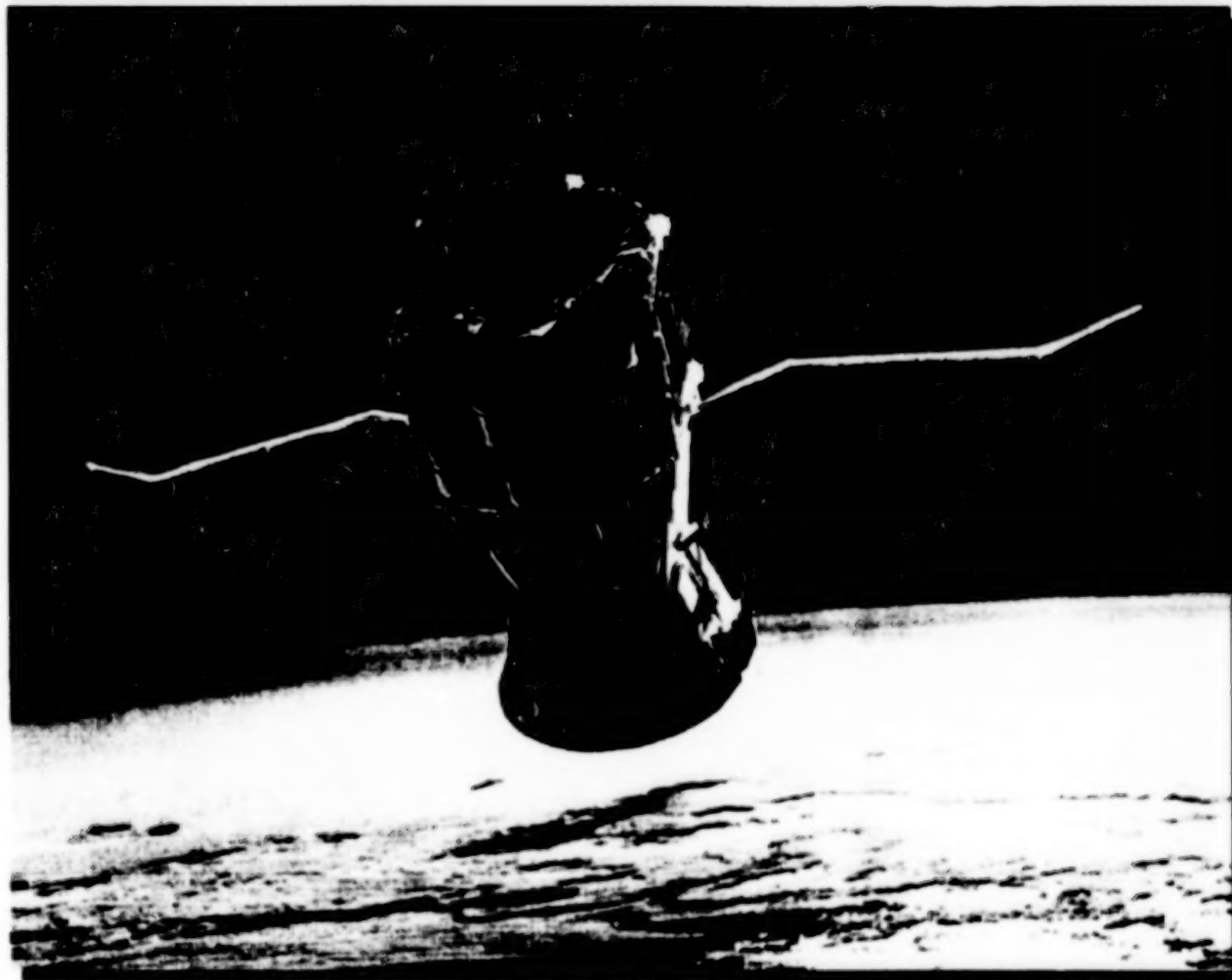
Solar Flare Nuclear Line Spectrum

- **OSSE spectrum of the intense obtained early in the CGRO mission**
 - Top panel is a prompt observation
 - Bottom is later in the event
- **Analysis of solar flare has revealed intense nuclear line spectrum**
 - Model fit shows the nuclear reactions associated with impulsive phase of flare lasted for over two hours and total energy in accelerated ions exceeded that in electrons
- **Many additional high-intensity flares are expected to be accessible as we approach next solar maximum**
- **Observatory will be oriented to facilitate rapid slewing of OSSE to the Sun as often as possible**

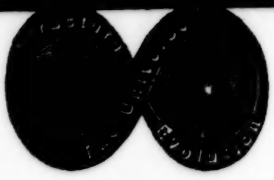




Submillimeter Wave Astronomy Satellite (SWAS)



<http://cfa-www.harvard.edu/cfa/oir/Research/swas.html>



SWAS

A Small Explorer for the Millimeter

- **SWAS is a complete radio astronomy observatory in space**
 - Now five months into its two-year mission
 - Has targeted more than 20 star forming clouds of gas in our galaxy
 - Has detected large amounts of water vapor coming from very cold (< -400 °F) gas
 - While water has been previously detected, this is the first detection in the most massive regions of interstellar space: the clouds of gas and dust that ultimately collapse to form stars and planets
- **Determining the abundance of water and molecular oxygen in these interstellar clouds is a key component in trying to understand the chemical reactions that create interstellar molecules and also to understand the process whereby these clouds of gas evolve and eventually collapse to form stars**



Star Formation and Molecular Cooling

The Chemical Evolution of Molecular Clouds

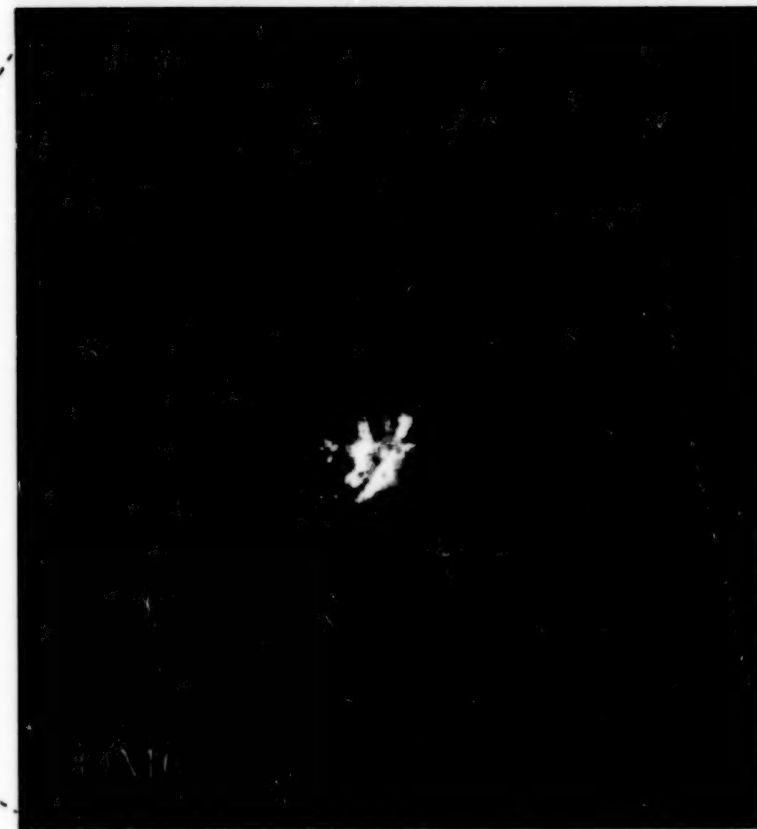
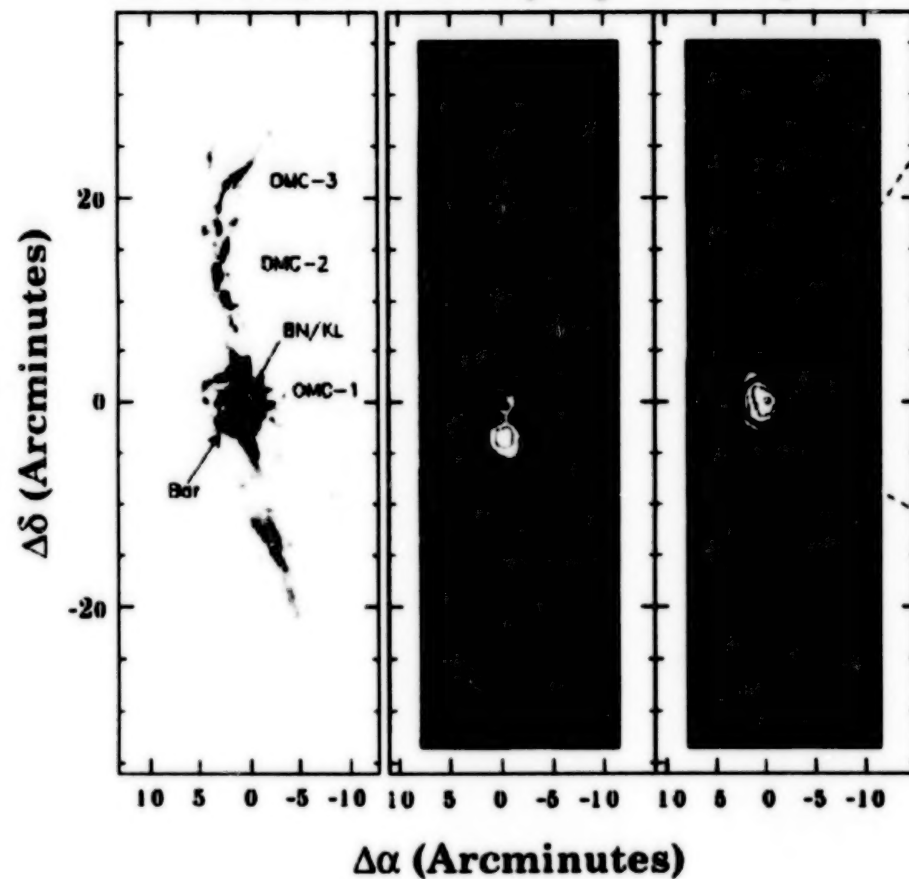
- **SWAS will observe molecules predicted to be principal coolants of star forming gas clouds**
- **Chemistry is an important factor in molecular cloud evolution and star formation**
 - SWAS will observe molecules that are central to interstellar gas cloud chemistry
- **The principal SWAS targets are dense parcels of gas and dust known as giant and dark cloud cores**
- **Other SWAS targets include**
 - External galaxies
 - Circumstellar envelopes
 - Planetary nebulae



SWAS

SWAS Maps

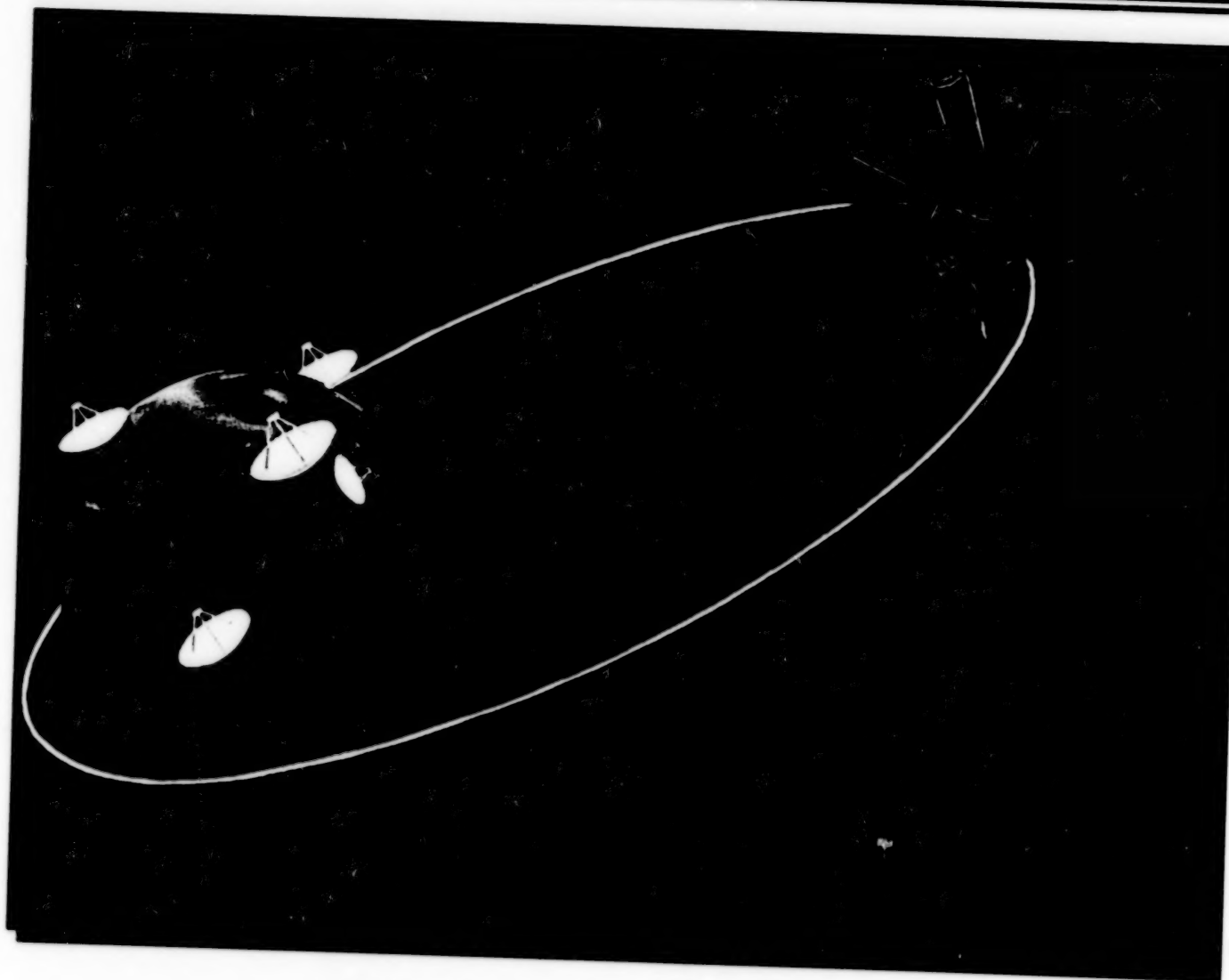
Dust (850 μm)* $\text{Cl } ^3\text{P}_1\text{-}^3\text{P}_0$ $^{13}\text{CO J=5-4}$



* Johnstone & Bally 1999, Ap. J., 510, L49.



HALCA



<http://www.vsop.isas.ac.jp/>



HALCA

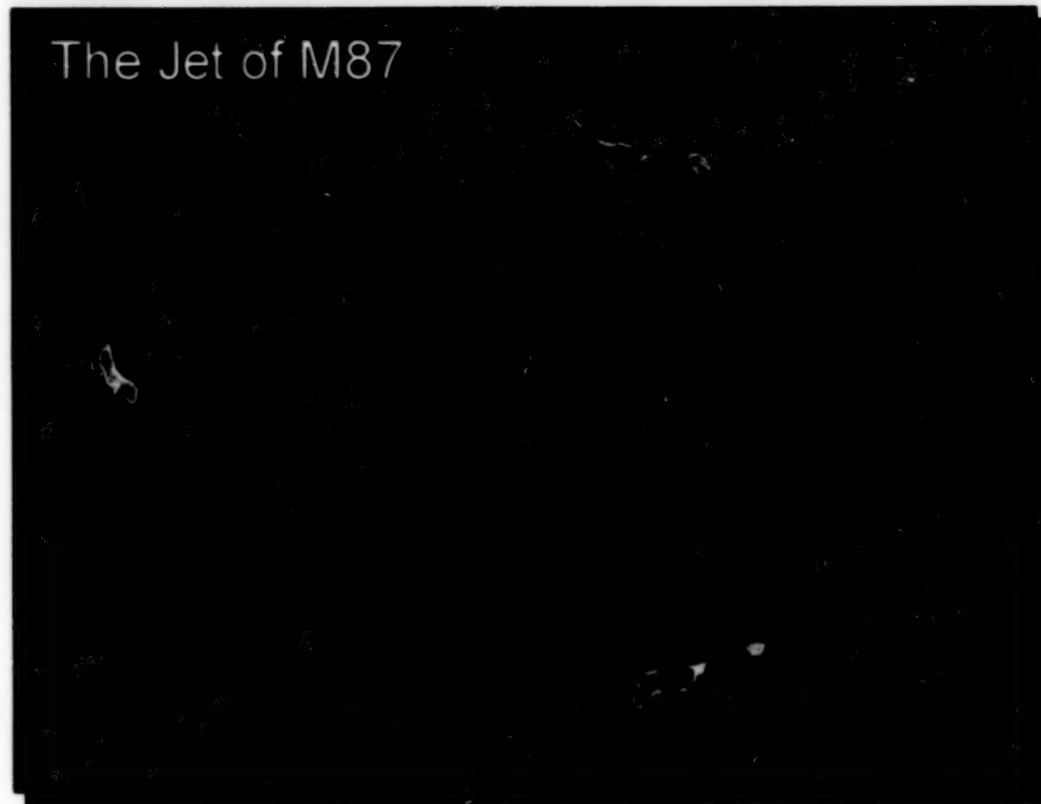
- **First technology test of the concept of space very long baseline radio interferometry on baselines up to three times longer than those achievable on Earth**
- **VSOP was successfully launched 12 February 1997 on the new ISAS M-V rocket from Kagoshima Space Center**
 - Successfully deployed 8 meter diameter radio telescope
- **HALCA is in an elliptical Earth orbit**
 - Apogee height of 21,000 km
 - Perigee height of 560 km



HALCA Science

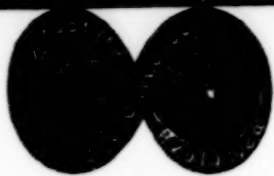
- **Science goal is to obtain very high angular resolution images of the central regions of active galaxies and active star forming regions**
- **HALCA started regular observations in Sept 1997 at 1.6 and 5 GHz**
 - 22 GHz data are not usable
- **There are problems with the data handling unit**
 - Observations are continuing

The Jet of M87



A 1.6 GHz (wavelength 18 cm) image of M87, the central galaxy in the Virgo Cluster, made from observations by the VLBA and HALCA

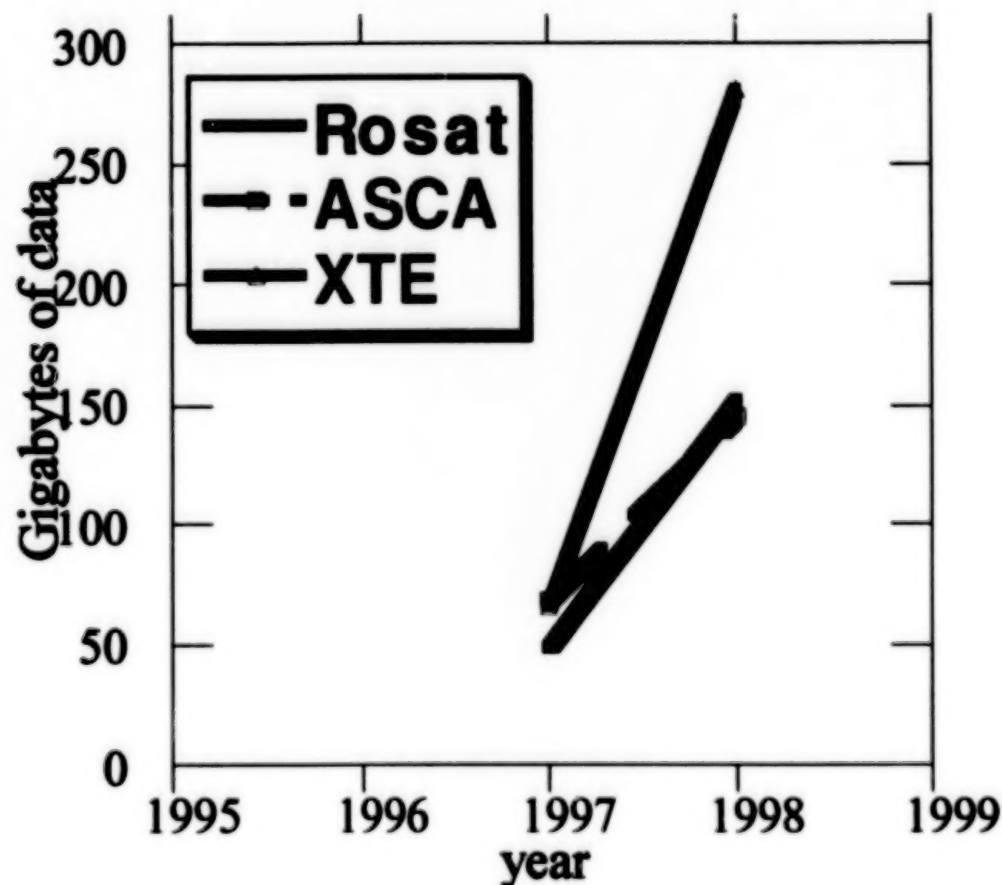
VSOP image: M. Reid, CfA



Continued Increase of Use of Extended Mission Data by the Community

Electronic access to extended mission data has dramatically increased ease of access of such data combined with the easy availability of analysis software has increased demand for extended mission data

Gigabytes of Data Transferred from
Archive Each Year

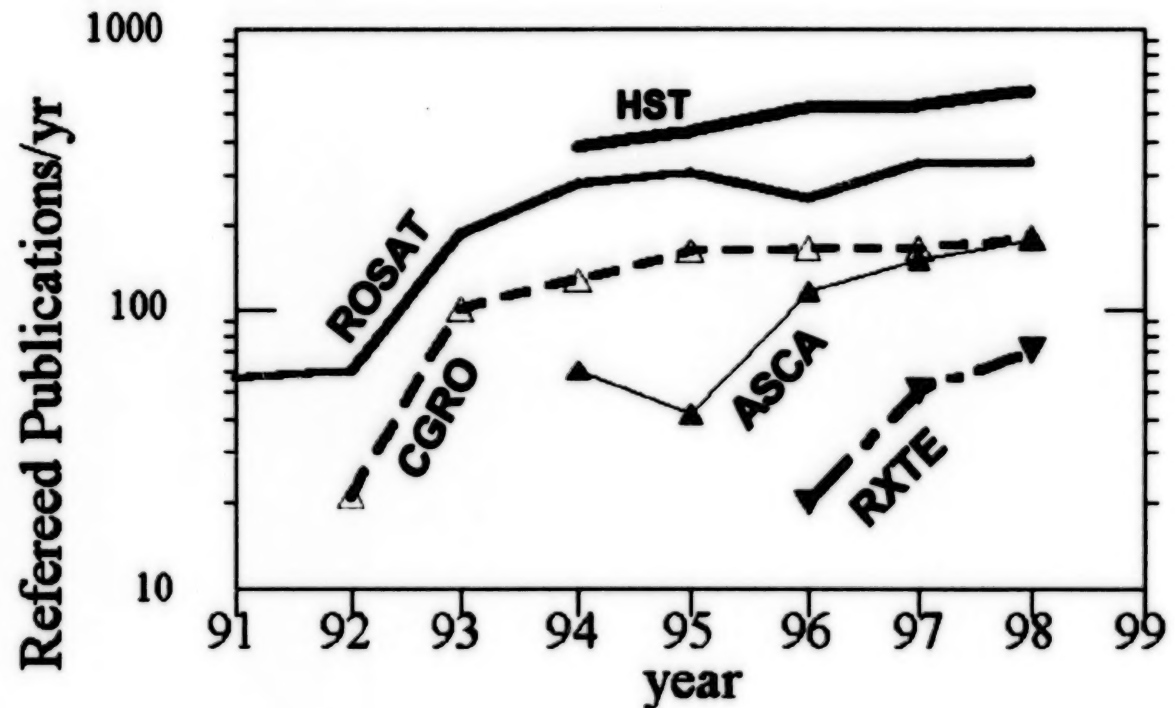




High Energy Missions Have the Same Total Publication Rate as HST

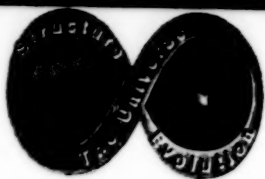
- U.S. Investment in international collaborations (ASCA, ROSAT) and low cost Explorer missions have paid off with a total publication rate similar to that of HST since the launch of ASCA

Publications Per Year

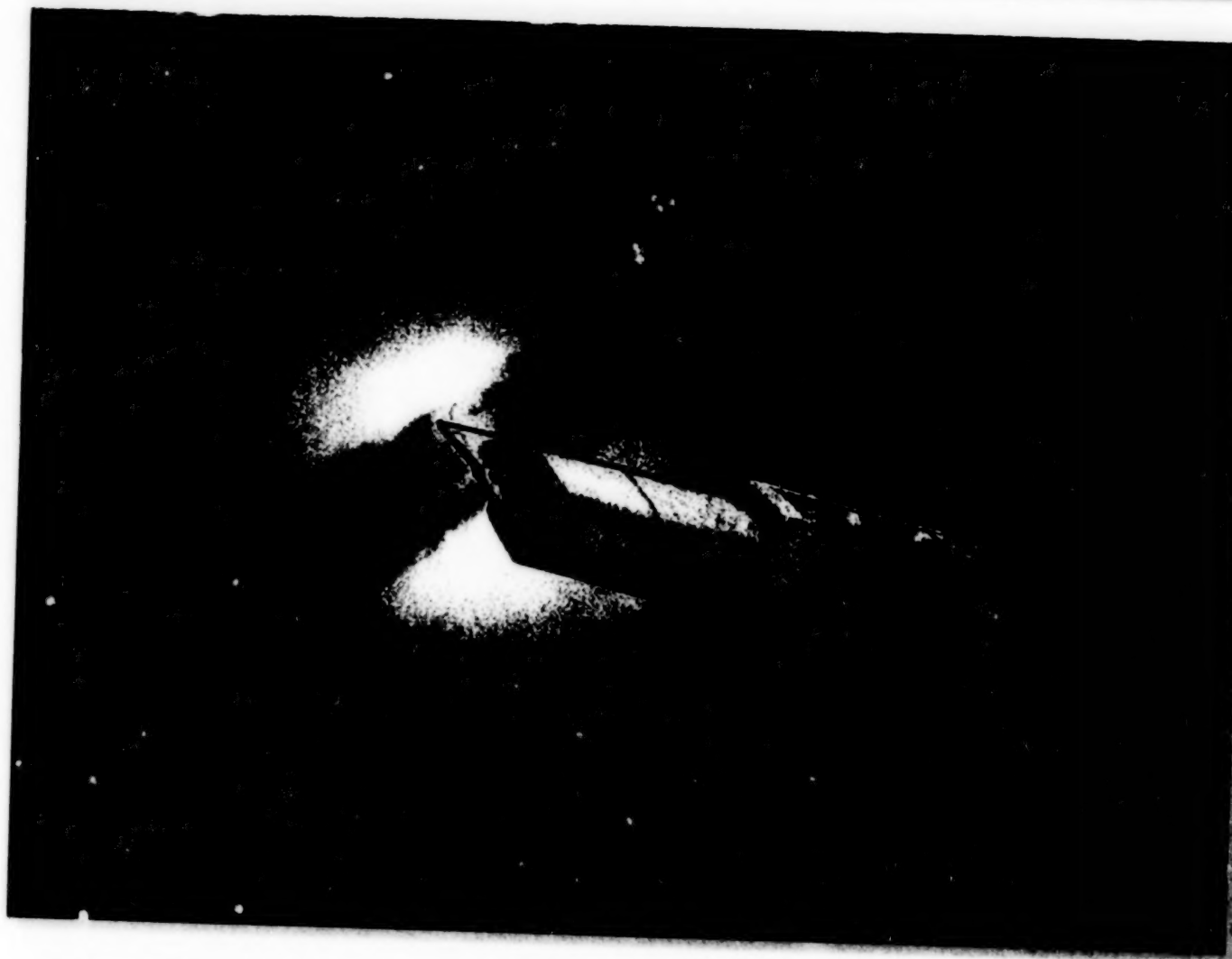


- All of these missions are international in character with considerable usage by European and Japanese scientists

- Many new scientific discoveries are being made using these "old" data



Astro-E



<http://hea-www.gsfc.nasa.gov/docs/xray/astroe/astroe.html>

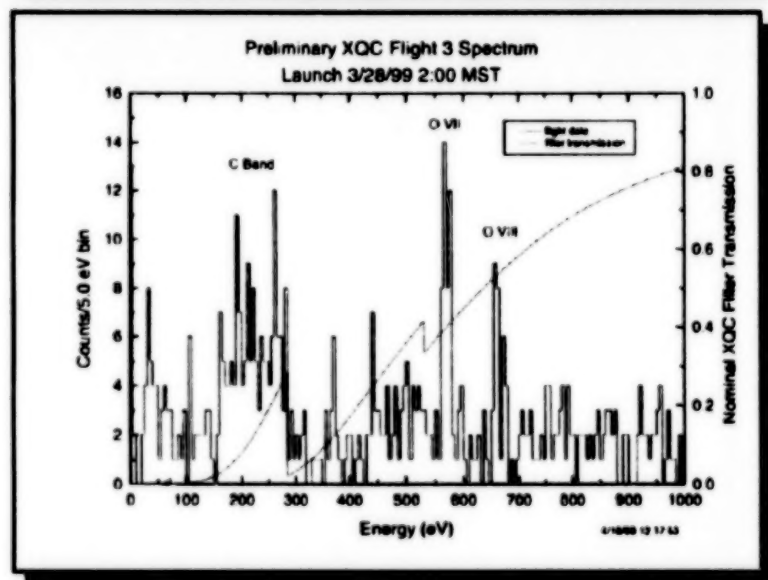


Astro-E — Status

- **Japanese-US Joint program**
 - U.S. provided X-ray telescopes, calorimeter (XRS from AXAF-S), and part of the CCDs — all delivered to Japan
 - Japan provided hard X-ray detectors, spacecraft, and mission operations
 - Software is joint effort
- **Five X-ray telescopes**
 - Four with CCDs
 - One with the calorimeter
- **Telescopes have ~ 20" FWHM and a 120" HPD**
- **All instruments obtain data simultaneously**
- **The US has 50% of the first two years during calorimeter phase and 40% after that**
- **Launch January 2000**



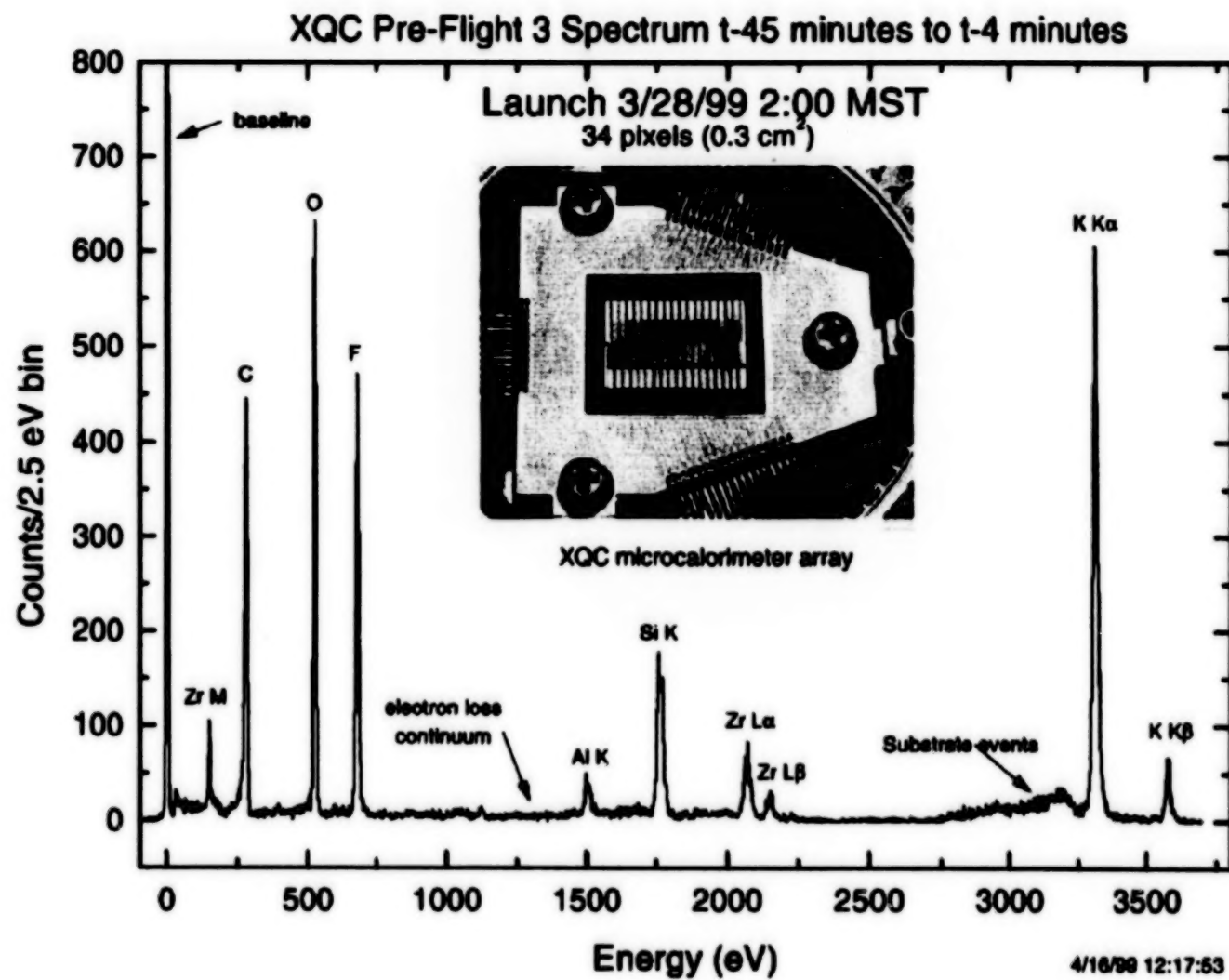
Astro-E - Science

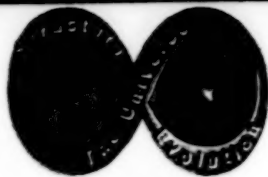


- XRS quantum calorimeter will provide high throughput, broad bandpass, high spectral resolution (~ 10 eV) imaging ($2' \times 4'$ FOV) data
- First flight opportunity, other than rockets, for this technology
- XRS is unique in ability to observe extended sources (galaxies, clusters, supernova remnants, etc.) and provide high efficiency high spectral resolution at $E > 3$ keV
- Will allow first measurement of dynamics and plasma diagnostics for a large number of celestial sources
- XRS operates at 60 mK and has a dewar lifetime of $\sim$ two years



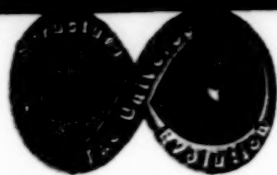
Astro-E



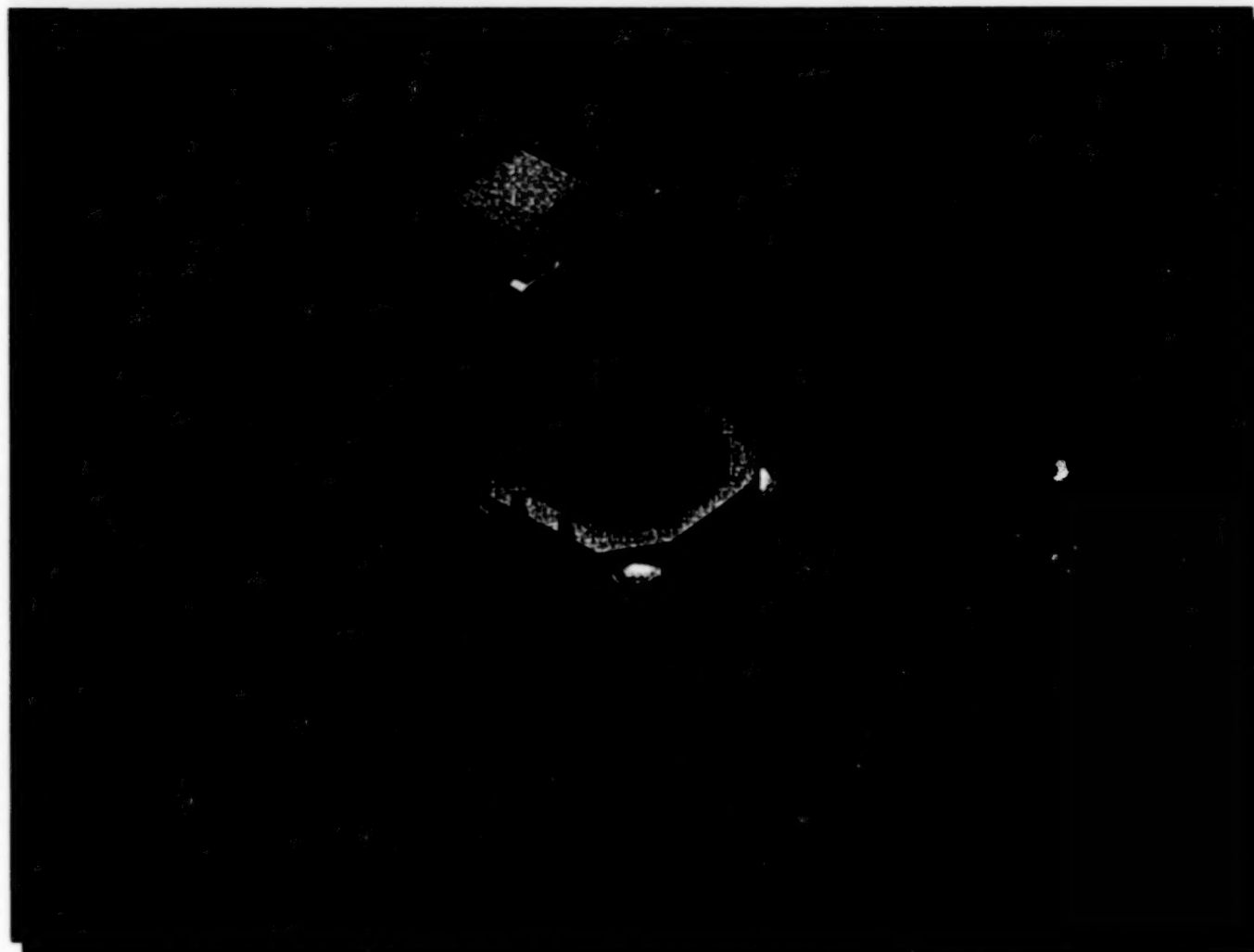


Astro-E

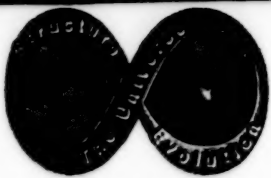
- **Hard X-ray detector should be order of magnitude more sensitive than HEXTE on XTE**
- **CCD cameras are basically an adjunct to the other two instruments but will provide factor of four more sensitivity than the comparable instrument on ASCA (about 1/2 of the area on XMM)**
- **Strength of Astro-E is**
 - Broad band pass
 - High spectral resolution
 - Moderate sensitivity



International Gamma-Ray Astrophysics Laboratory (INTEGRAL)

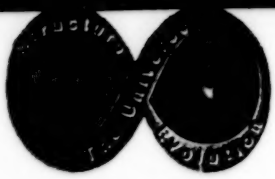


<http://astro.estec.esa.nl/SA-general/Projects/Integral/integral.html>



INTEGRAL

- **The scientific goals of INTEGRAL are addressed through the use in the gamma ray domain of high resolution spectroscopy with fine imaging ($\sim 10'$) and accurate positioning of celestial sources**
- **ESA mission with USA and Russian contributions**
 - US Participation in European lead instruments and data center
- **The spectrometer SPI (SPectrometer on INTEGRAL) will operate in the 20 keV–8 MeV energy range with an energy resolution of 2 keV (FWHM) at 1 MeV**
 - Accomplished using array of 19 hexagonal high purity Germanium detectors cooled by a Stirling cooler system to 85 K
 - $\sim 100\times$ more sensitive than HEAO-3
- **IBIS provides**
 - Diagnostic capabilities of fine imaging (12 arcmin FWHM)
 - Source identification
 - Spectral sensitivity to both continuum and broad lines over a broad (15 keV–10 MeV) energy range



INTEGRAL

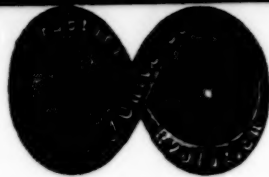
Scientific topics to be addressed by the Spectrometer

- **Nucleosynthesis Processes and Supernova Dynamics**

- Astrophysics of supernovae
- Historical supernovae and recent massive star formation
- Nucleosynthesis in massive stars and the mapping of sites of star formation
- Extragalactic supernovae
- Astrophysics of novae
- Cosmological abundances and the nucleosynthesis of light elements

- **Interstellar Processes**

- Diffuse galactic 511 keV emission
- Energetic particles: nuclear de-excitation lines



INTEGRAL

- **US is providing**
 - Pulse Shape Discrimination and electronics for SPI (collaboration with France)
 - Software for SPI
 - Co-Investigator for IBIS (no hardware)
- **Status: Hardware and software are on schedule**
- **Launch is April 2001 (Proton)**



X-ray Multi-Mirror Mission (XMM)

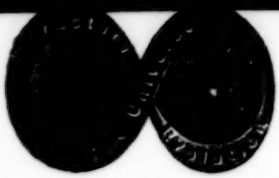


http://astro.estec.esa.nl/XMM/xmm_top.html

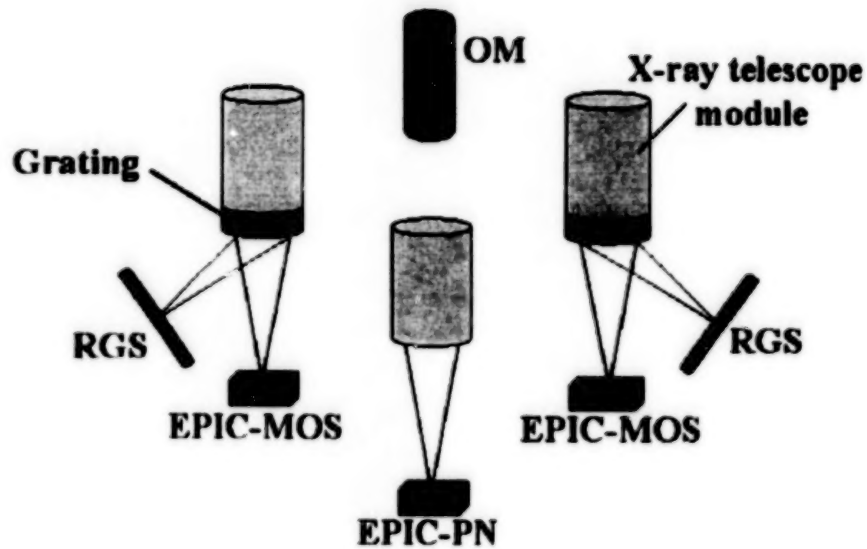


X-ray Multi-Mirror Mission (XMM)

- **XMM is an international collaboration between ESA, NASA, and a large number of European countries**
 - NASA has a letter of agreement in place with the Netherlands and the United Kingdom
- **XMM flies three large collecting area telescopes with CCDs and moderate area, high spectral resolution X-ray spectroscopy using gratings**
- **With a sensitivity for X-ray spectroscopy roughly 20 times more sensitive than ASCA, XMM will provide large samples of objects and probe to high redshifts**
- **The combination of XMM and Chandra will provide unique spatial and spectral information**

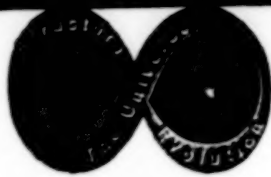


X-ray Multi-Mirror Mission (XMM)



- **XMM has 3 focal plane instruments**
 - EPIC, a CCD imaging spectrometer similar to those on Chandra, Astro-E, and ASCA
 - Two RGS gratings
 - > U.S. provided grating
 - Optical Monitor
 - > U.S. provides electronics, software
 - Current Status
 - > Hardware is undergoing integration and testing with spacecraft
 - > Launch January 2000

- **Has a deep 48-hour orbit with almost continual ground contact**
- **All five instruments work simultaneously**



X-ray Multi-Mirror Mission (XMM)

- **The gratings provide high resolution ($R = 200\text{--}800$) in the 0.3–2 keV band for small and point-like sources**
- **The Optical Monitor provides simultaneous optical and UV spectral and timing data for such objects as**
 - Flare stars
 - Cataclysmic variables
 - Active galaxies
- **The new technology mirrors have a 6" FWHM and a 14" HPD**
- **XMM has roughly the RXTE counting rates but can observe sources 10^5 times fainter**
 - Cannot make timing observations of "bright" sources due to pile-up effects and telemetry limitations



Chandra X-Ray Observatory (CXO)



William T. Huddleston
NASA Headquarters
<http://asc.harvard.edu/>

Chandra 1

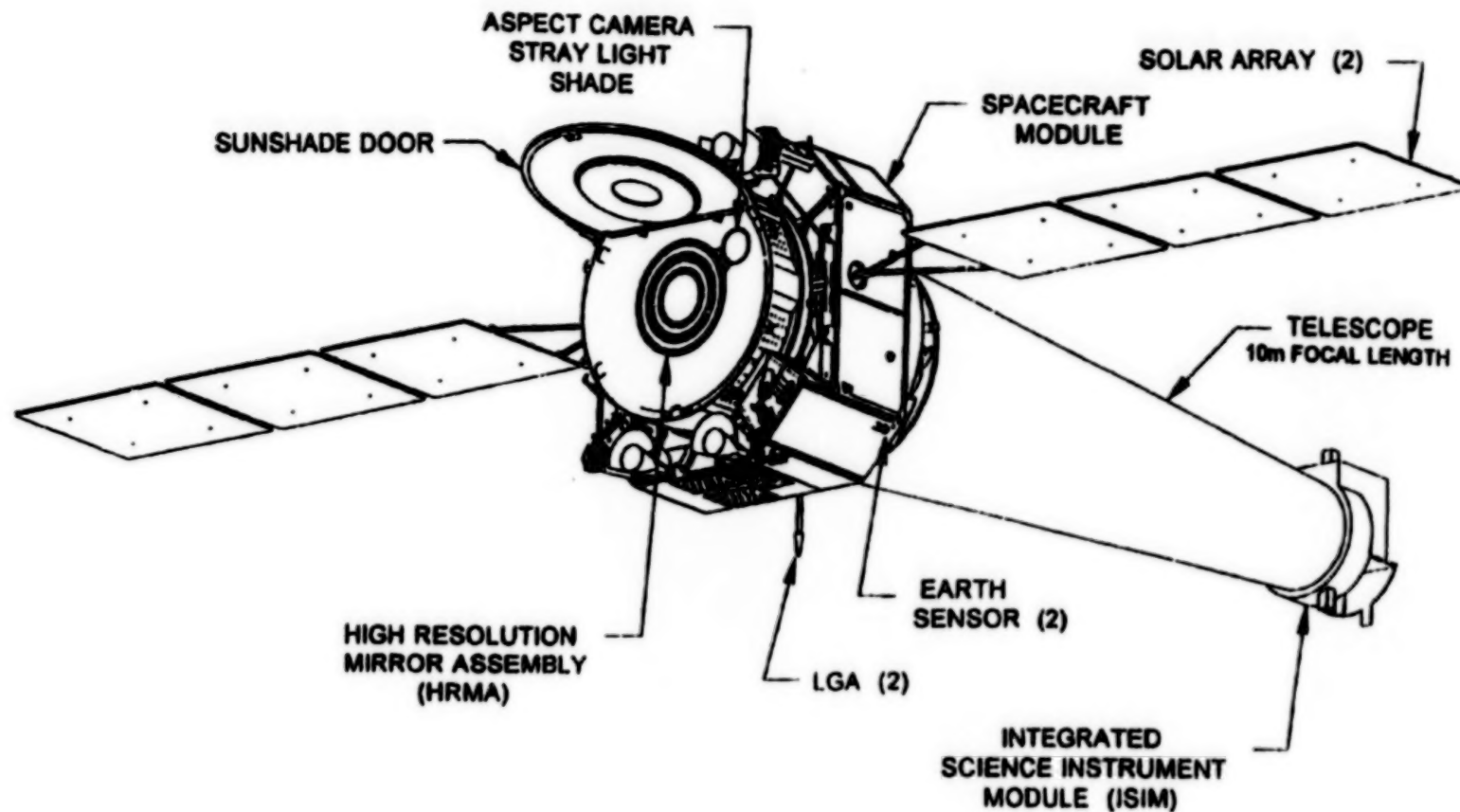


Briefing Content

- **CXO Exploded & Deployed View**
- **Major Program Responsibilities**
- **Science Objectives/Success Criteria**
- **Mission Facts**
- **Launch & Early Orbit Events**
- **Pre/Post Deployment Timeline**
- **Chandra Timeline Overview**
- **Operations Concept**
- **Status**
- **Major Activities/Reviews Remaining**
- **Budget**
- **Residual Risks**
- **Executive Schedule**
- **Photo**

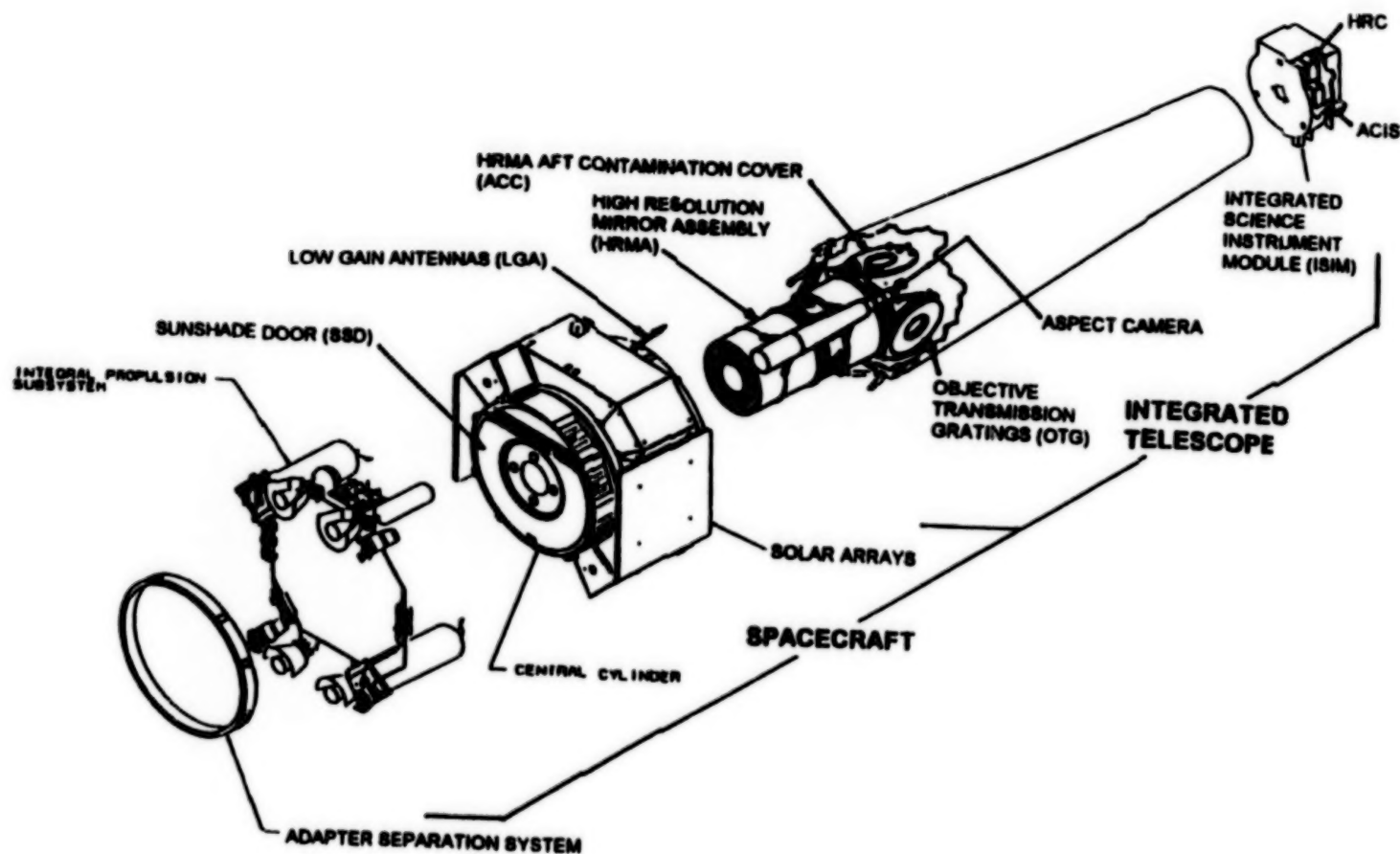


Chandra X-Ray Observatory Deployed View





Chandra X-Ray Observatory Exploded View





Major CXO Program Responsibilities

- **Program Executive:** William T. Huddleston
- **Program Scientist:** Dr Alan N. Bunner
- **Program Management:** Fred S. Wojtalik
- **Project Scientist:** Dr. Martin C. Weisskopf
- **Observatory Development:** Craig Staresinich, Program Manager
 - **Spacecraft**
 - **Mirrors**
 - **Telescope**
 - **Science Instrument Module**
 - **Instruments**
 - > **ACIS**
 - > **High Resolution Camera**
 - > **High Energy Transmission Grating**
 - > **Low Energy Transmission Grating**
 - **Integration & Test**
- **Payload Integration & Test**
- **Operations Capability Development**
 - **Operation Control Center-online System**
 - **Offline System**
 - **Science Center**
- **Operations**
 - **Program Management**
 - **Operations Control Center**
 - **Deep Space Network**
- **Inertial Upper Stage**

HQ, Office of Space Science
HQ, Office of Space Science
Marshall Space Flight Center
Marshall Space Flight Center

TRW

TRW

Raytheon/Optical Coating Laboratory

Eastman Kodak Company

Ball Aerospace

Massachusetts Institute of Technology
Smithsonian Astrophysical Observatory
Massachusetts Institute of Technology
Space Research of Netherlands

TRW

TRW

MSFC

MSFC

Computer Science Corporation

Smithsonian Astrophysical Observatory

MSFC

SAO

Jet Propulsion Laboratory

Boeing Company



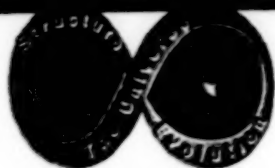
Science Objectives/Mission Success Criteria

- **Science Objectives:**

- Determine the nature of celestial objects from normal stars to quasars.
- Understand the nature of physical processes which take place in and between astronomical objects.
- Understand the history and evolution of the universe.

- **Mission Success:**

- Chandra's scientific success relies on successful operation of the observatory and its instruments.
- There are, however, a number of scientifically degraded modes of operation that are capable of producing extraordinary valuable and unique scientific data.
 - > Loss of one or both gratings.
 - > Loss of an entire focal plane instrument.
 - > Partial loss of the second focal plane instrument as long as some imaging capability is available.



Chandra X-Ray Observatory Mission Facts

- **Space Shuttle Launch Date** July 9, 1999 (STS-93); 0118 EDT
- **Orbit** 6,214 statute miles (10,000 km)
perigee x 86,992 miles (140,000 km) apogee; 64 hour orbit
- **Operational Life** 5 years (15 years design life)
- **On-Orbit Weight** 12,930 lbs.
- **Launch Weight (CXO + IUS)** 50,162 lbs
- **Operational Width** 45.3 Feet
- **Operational Length** 64.0 Feet
- **Mirror Assembly** 4 mirror pairs; Each 2.62 Feet in length; 1.97-3.94 Feet Diameter; Focal 32.8 Feet (10 Meters)
- **Science Instruments** High Resolution Camera;
AXAF CCD Imaging
Spectrometer; High & Low Energy
Transmission Gratings



CXO Mission Facts (continued)

- **Science “system level” verification conducted at X-Ray Calibration Facility, MSFC**
 - “Most thorough X-Ray calibration (including 104 ‘vacuum days’ of system-level testing) ever performed” - Dr. Martin C. Weisskopf, Project Scientist.
 - System level testing/calibration key results:
 - > Encircled energy (image quality) in 1 arc second
 - Level 1 requirements: > 60% at 0.93 keV, > 19% at 8.04 keV
 - Based on measured results: > 70% at 0.93 keV, > 50 % at 8.04 keV
 - > Nominal HRMA resolution
 - Effective Level 1 requirement: 0.5 seconds of arc
 - Measured results: < 0.2 seconds of arc
 - On-Orbit performance: < 0.5 seconds of arc
 - > Instruments all meet or exceed Level 1 requirements with minor variances

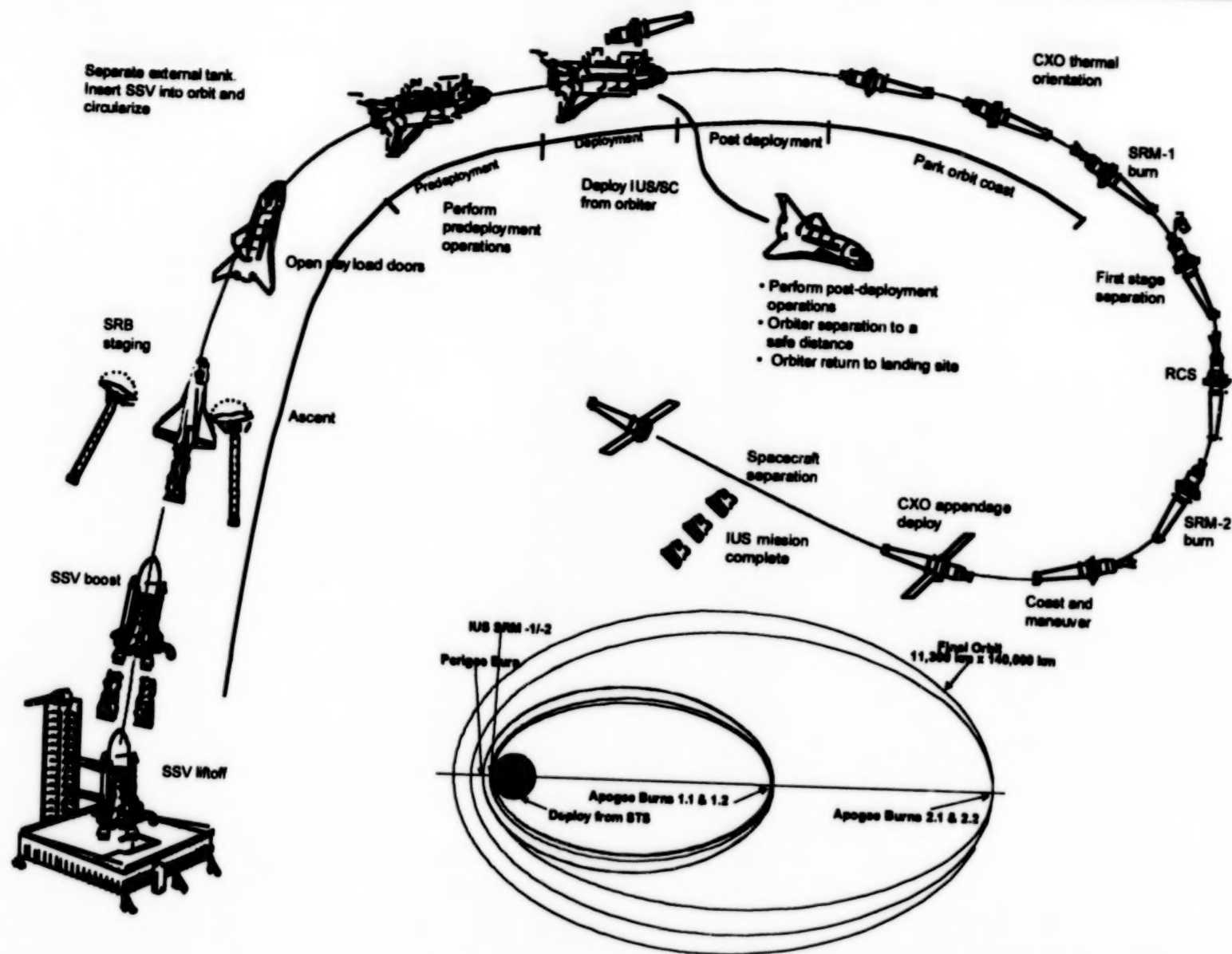


CXO Mission Facts (continued)

- **Projected “system level” performance:**
 - X-Ray benchmark: (Einstein Observatory - 1978-1981)
 - > 100 times more powerful detecting X-Rays; Images 10 times sharper
- **Resolution:** “The CXO’s resolving power is equal to the ability to read the letters of a stop sign at a distance of 12 miles.”
- **Smoothness of mirrors:** “If the state of Colorado were as smooth as the Chandra mirrors, Pike’s Peak would be less than an inch tall.”



Launch and Early Orbit Events





Pre-Deployment Timeline

Event	Mission Elapsed Time, MET (Hr : Min)
	Deploy Rev 6
Liftoff	0:00
OMS-2 Cutoff	0:43
Configure GPCs for OPS 2	0:53
Start Tracking Arc	1:00
Maneuver to PLBD Opening Attitude	1:12
PLBD Operations	1:28
AXAF Powerup	1:30
AXAF Communication Activation	1:40
Activate and Checkout PCP/CIU	2:03
AXAF RF Check (Upper LGA)	2:20
Initiate IUS Pre-deployment Checkout	2:30
Stop Tracking Arc	3:00
Actuator Engagement	3:05
Orbiter to IUS State Vector Transfer	4:05
Maneuver to Deploy Attitude	5:21
Raise Tilt Table to 29 degrees	5:35
RF Check (Lower LGA)	5:50
IUS PI Lock at 16 KBPS	6:30
IUS and AXAF to IUS Internal Power	6:57
Go for Deploy	7:05
Umbilical Release	7:07
Raise Tilt Table to 58 degrees	7:09
IUS/AXAF Deploy	7:17

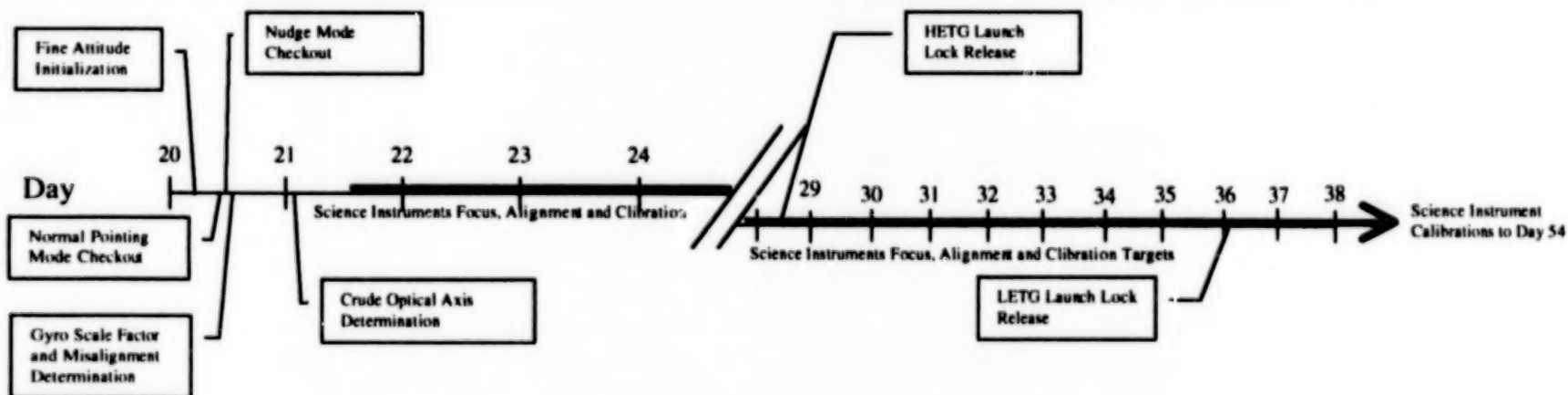
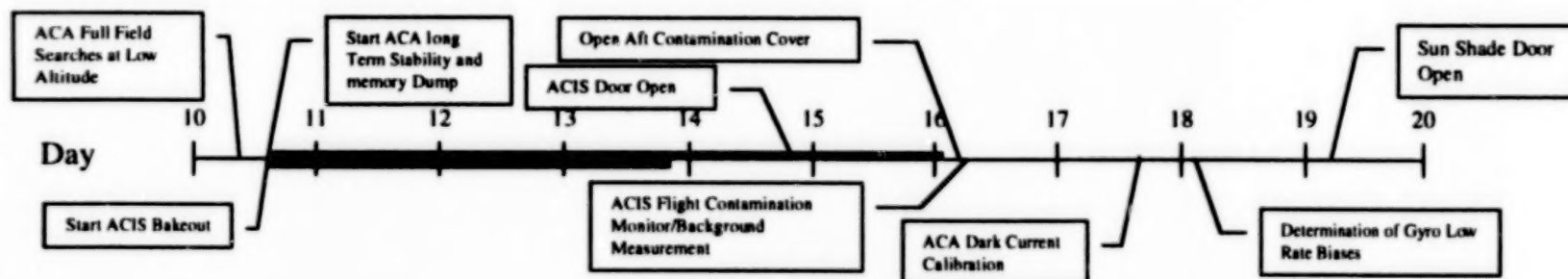
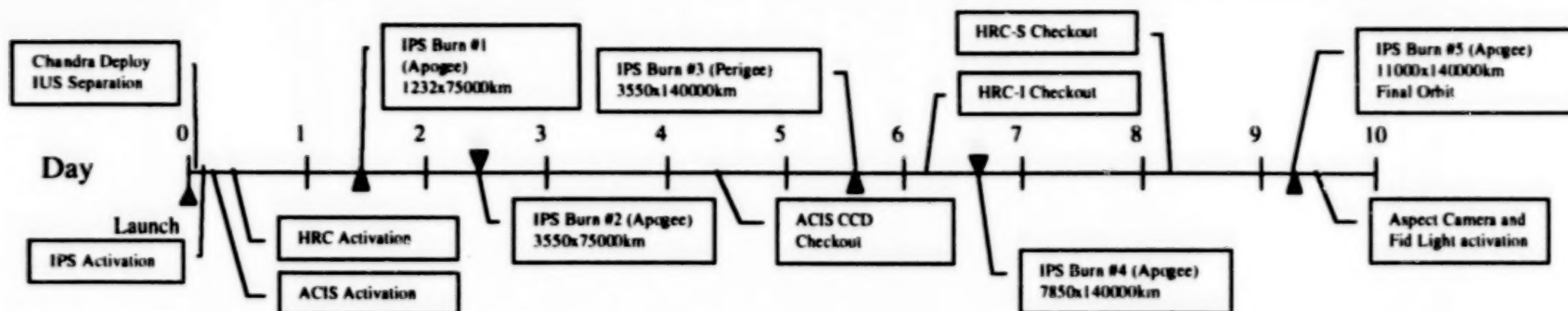


Post-Deployment Timeline

Event	MET (Rev 6)
Deployment from Orbiter	7:17
AXAF Downlink On	8:14
SRM-1 Ignition	8:17
SRM-1 Burnout	8:19
Stage 2 Battery On / Stage 1 Battery Off	8:20
Stage 1/2 Separation	8:21
SRM 2	8:22
SRM 2 Burnout/Start 4 minute outgassing period	8:24
Maneuver to AXAF attitude	8:28
Start hold for AXAF thermal conditioning	8:31
DGS Rise	8:33
Inhibit RCS/ Start solar array deployment	8:46
Enable RCS/Hold for AXAF activation	9:01
OTS Rise	9:11
IUS-AXAF Separation	9:18
MAD Rise	9:51 (6°)
IUS mission complete (latest)	9:26



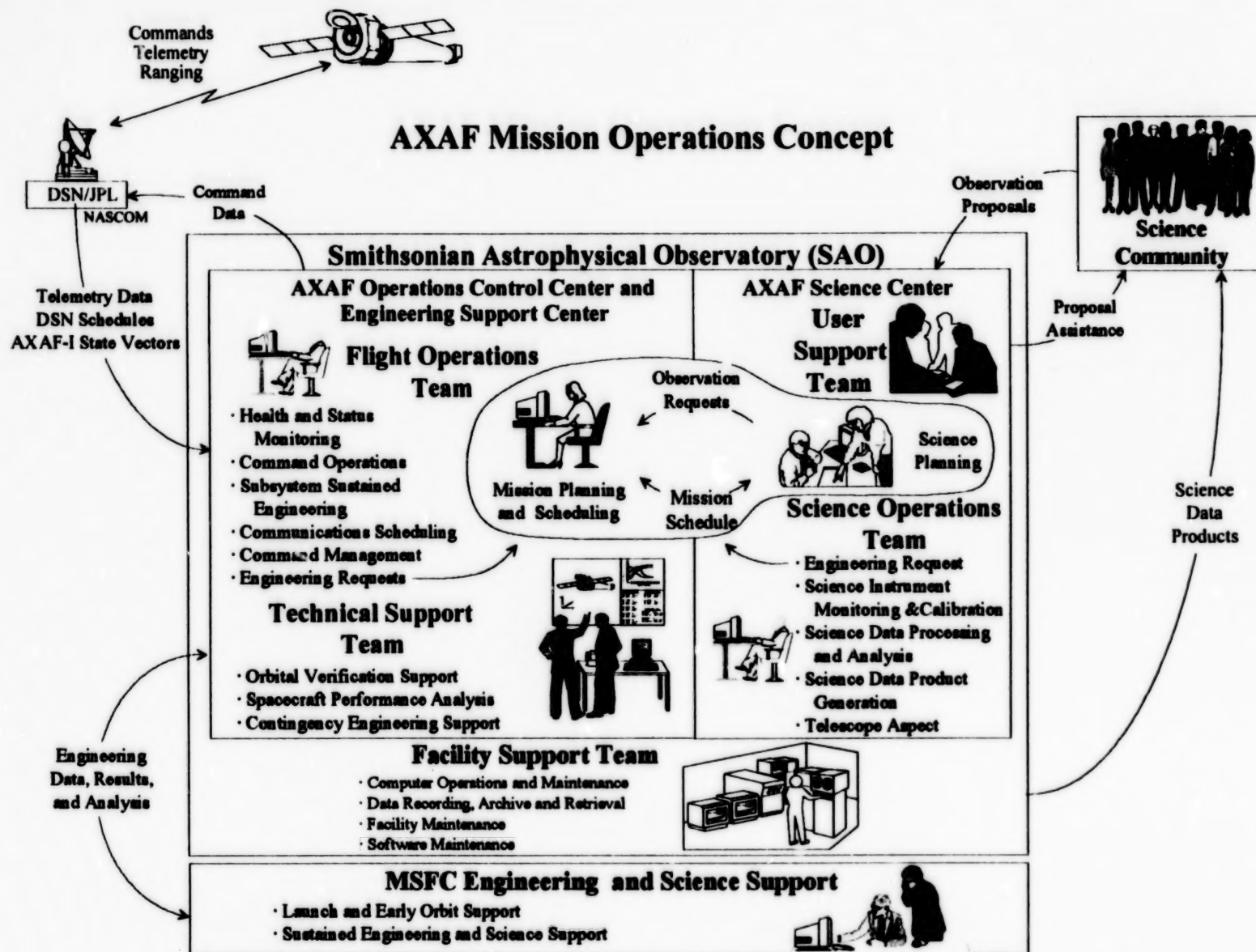
CXO Timeline Overview



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CXO Mission Operations Concept





Chandra Status

(AS OF 4-21-99)

- Chandra shipped to KSC on 2/4/99
- Command & Telemetry Unit and Interface Unit reintegrated with S/C with successful regression testing – 3/16/99
- State of Health Test – 3/17/99
- Mission Readiness Review/Flight Readiness Review-1 – 3/23/99
- Payload Operations Procedures (POP) test – 3/30/99
- Solar Array Installation & Fuel – 3/22/99-4/15/99
- Mechanical mate of Inertial Upper Stage (IUS) to CXO – 4/27/99
- Electrical mate of IUS to CXO – 4/30/99
- AXAF CCD Imaging Spectrometer flight door opening – 5/2/99
- Mission Readiness Review/Flight Readiness Review-2 – 6/15/99
- CXO/IUS transfer to Pad – 5/28/99
- Orbiter/Payload integration – 6/10/99
- Launch on July 9, 1999



Major Activities/Reviews Remaining

- **Mission Readiness Review/Flight Readiness Review-1** 03/23/99
- **ACIS Flight Door Opening** 05/08/99
- **Payload Readiness Review - KSC** 05/27/99
- **IAT& EIRR Readiness Briefing To HQ** 06/09/99
- **Program Management Readiness Briefing to HQ** 06/10/99
- **ACIS EM Door Opening** 06/11/99
- **Terminal Count Down Demonstration** 06/16/99
- **Science Press Conference** 06/21/99
- **Launch Readiness Review - KSC** 06/22/99
- **Flight Readiness Review - KSC** 06/25/99
- **Science Press Conference** 07/07/99
- **L-1 Review** 07/08/99
- **Launch** 07/09/99



CXO Budget (\$ M)

	PRIOR	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	BTC	TOTAL
ADVANCED TECH DEV	54.2								54.2
DEVELOPMENT	1,469.7	39.0							1,508.7
MO & DA	169.9	55.9	60.5	59.7	61.6	59.7	49.2	225.2	741.3
UPPER STAGE	73.9	2.0							75.9
STS LAUNCH SUPPORT	268.0	114.9							382.9
TRACKING & DATA SUPPORT	1.5	0.2	0.2	0.2	0.2	0.2	0.2	0.3	3.0
FACILITY CONSTRUCTION	17.7								17.7
TOTAL	2,054.9	211.6	60.7	59.9	61.8	59.9	49.4	225.5	<u>2,783.7*</u>

* These estimates include cost growth associated with launch slips experienced over the past two years.

> About 3% growth in the Development cost (\$ 47.1 M)

> About 7% growth in the Upper Stage



Residual Risk

Walk-on Chart



Chandra to KSC 2/4/99



Chandra 20

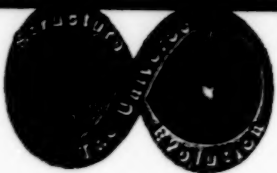
CX0

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Preparation of Observatory At KSC





CXO in Vertical Processing Facility

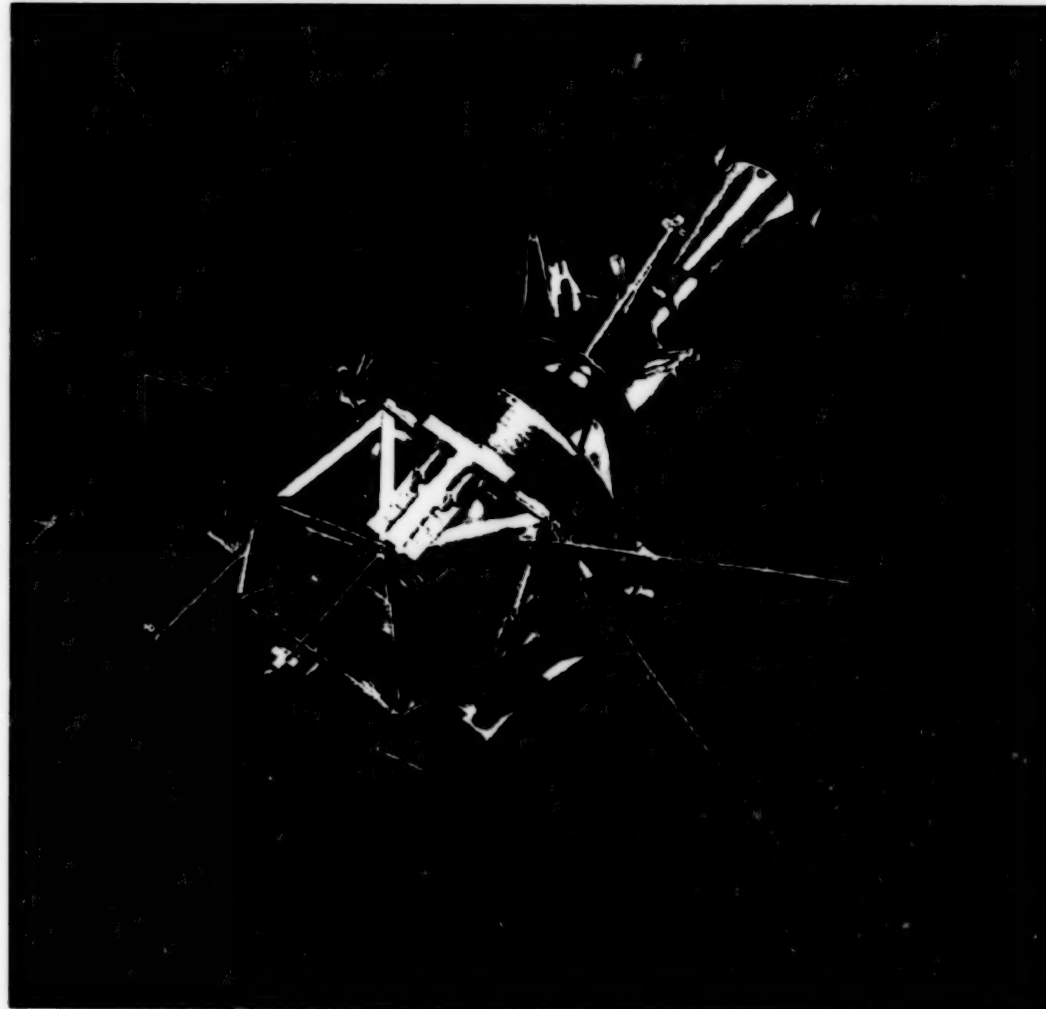
3-24-99





Gravity Probe-B

The Relativity Mission

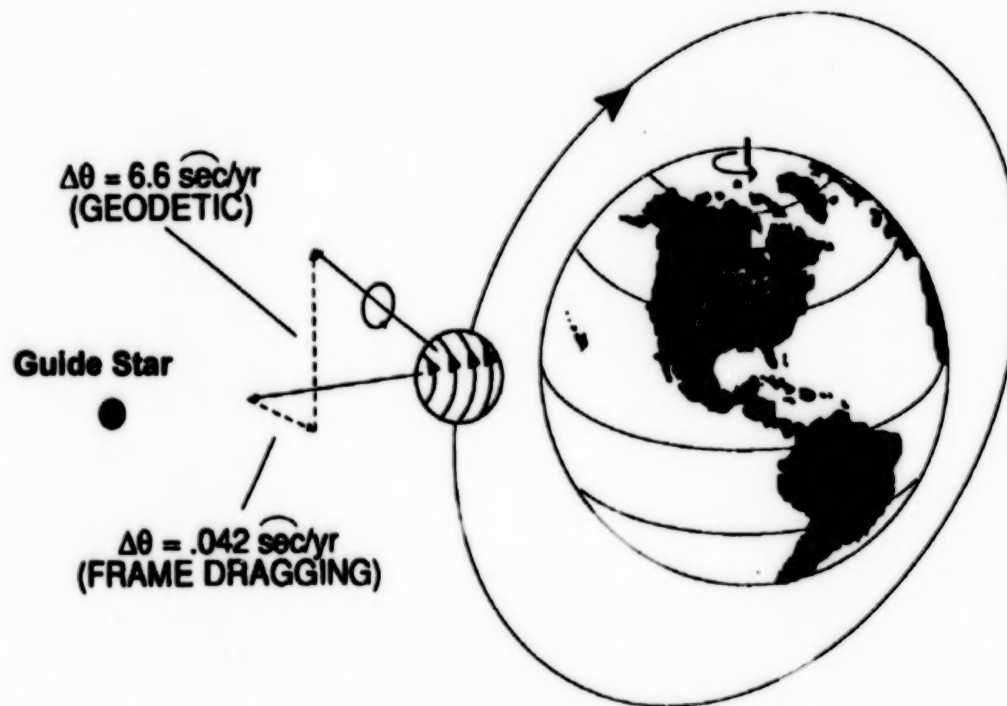


Rex D. Geveden
Marshall Space Flight Center
<http://einstein.stanford.edu/>



Scientific Objectives

- The objective of the GP-B experiment is to test two predictions of Einstein's theory of general relativity:
 - The Lense-Thirring effect, "frame-dragging" by rotating matter, (approx. 42 milli-arc-seconds per year); and,
 - The space-time curvature known as the "geodetic effect," (approx. 6600 milli-arc-seconds per year).
- Science requirements
 - Measurement Accuracy:
 - > 0.5 milliarcsec/yr.
 - Science Data Collection
 - > not less than 12 mos.





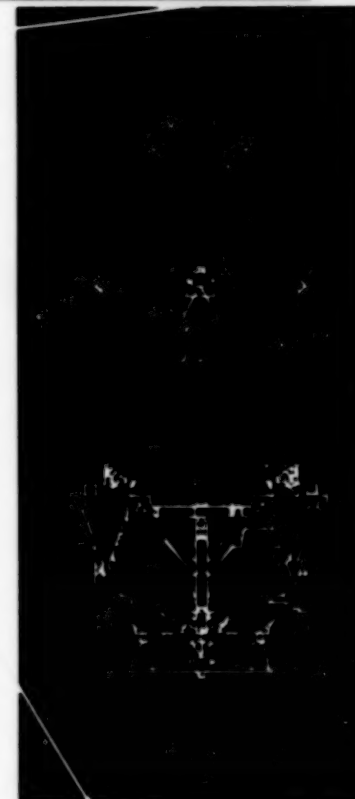
Mission Definition

- **Launch**

- Date: October 26th, 2000
- Vehicle: Delta II (7920)
- Location: VAFB, SLC-2W

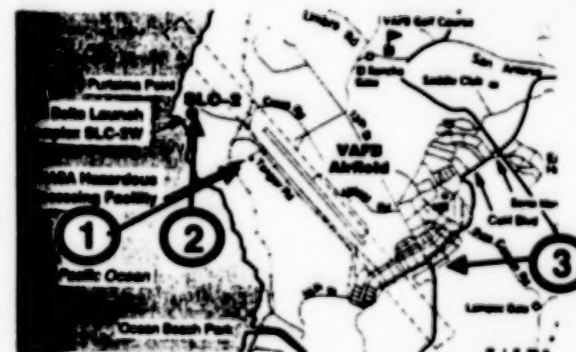
- **Orbit**

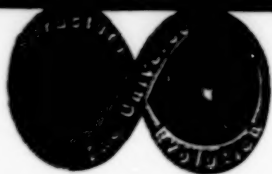
- Polar, circular
 - > 0.00134 ± 0.0005 eccentricity
 - > 90 ± 0.03 deg inclination
- 650 km altitude
- "Drag Free" control about the first gyro



- **Timeline**

- Launch through Day 40: Initialization and checkout
 - > system activation
 - > orbit trim
 - > gyro spinup and alignment
- Day 40 through 14 months: Normal science
- Months 15 & 16: Post-mission calibration



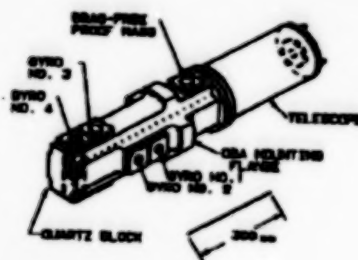


Flight Hardware

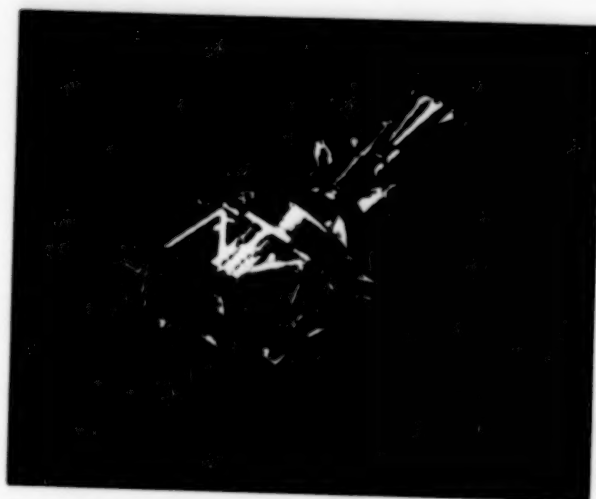
GYROSCOPE & HOUSING



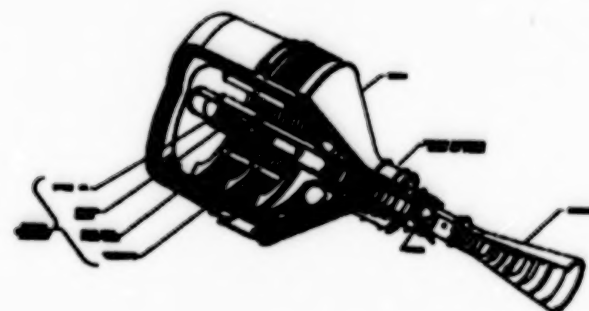
SCIENCE INSTRUMENT ASSEMBLY



PROBE WITH SCIENCE INSTRUMENT ASSEMBLY



SPACE VEHICLE: PAYLOAD
INTEGRATED WITH SPACECRAFT



SCIENCE MISSION PAYLOAD:
DEWAR WITH PROBE &
SCIENCE INSTRUMENT ASSEMBLY

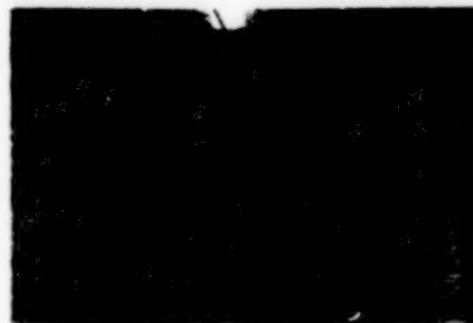


Science Instrument Description

- **Science Instrument Baseline**

- Quartz Block
- Fused Quartz Star-Tracking Telescope
- 2 Detector Package Assemblies
- 4 Gyroscopes
- 4 Gyro Spin-up Plumbing Assys
- 4 Gyro Caging Assys
- 4 Local Superconducting Nb Shields
- 4 SQUID Packages on 2 brackets with temp. control

- **The Science Instrument integration is complete.**

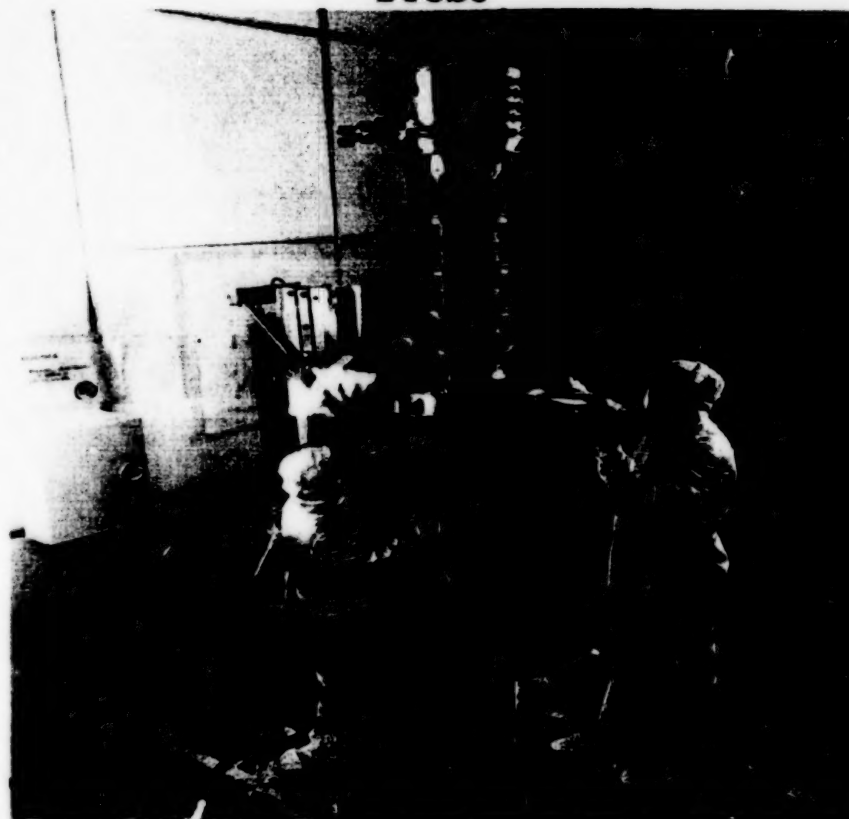




Payload

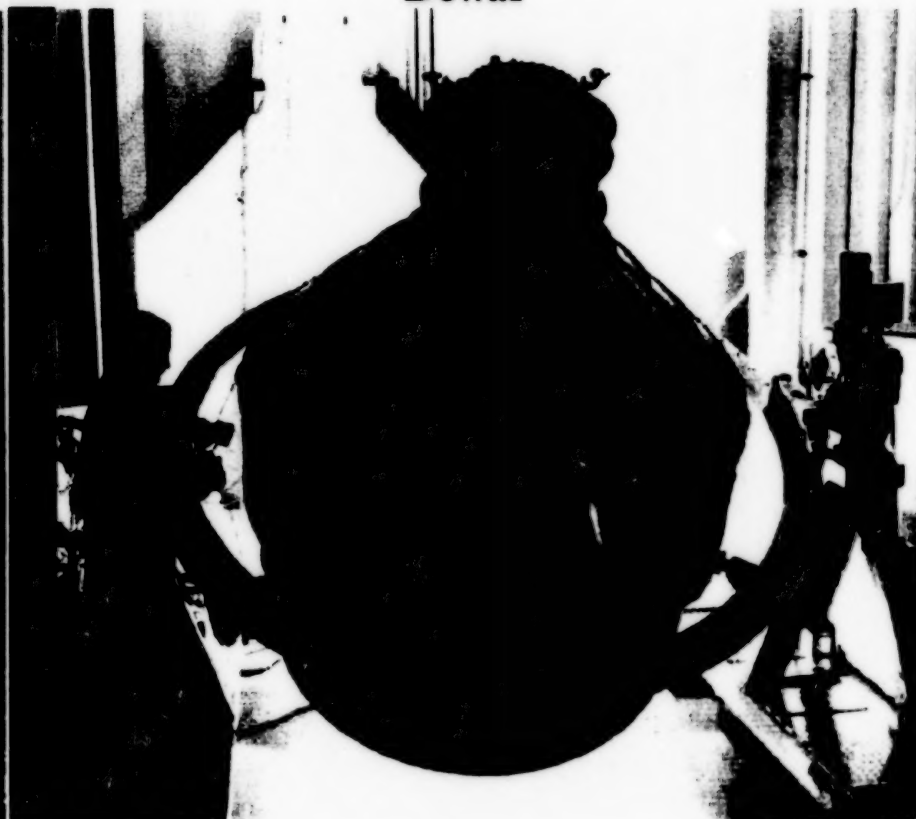
- The Payload is complete.

Probe



As the interface between the Science Instrument and the Dewar, the flight Probe must withstand temperature extremes from near absolute zero to room temperature.

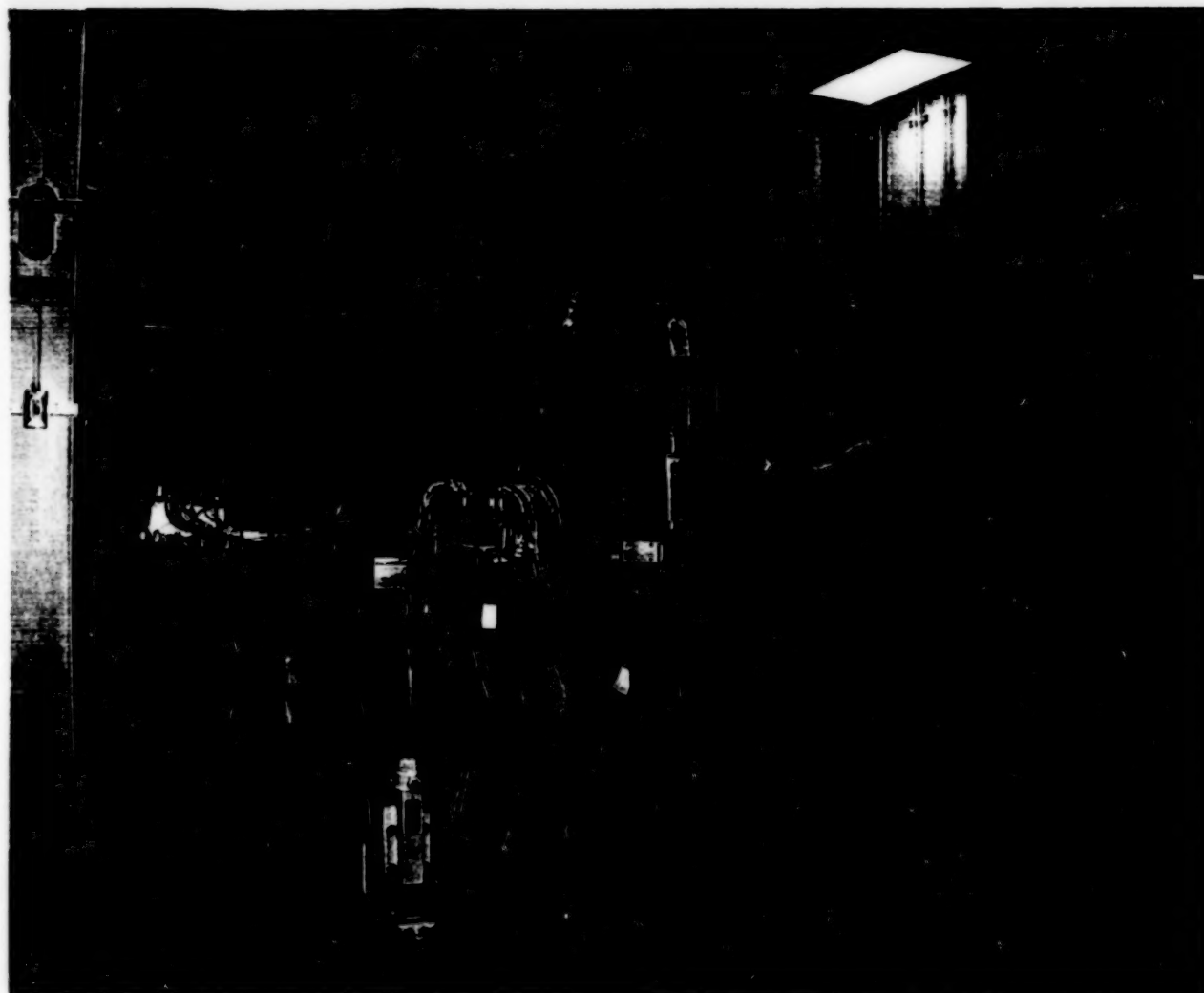
Dewar



With a capacity of 2400 liters, the GP-B Dewar is the largest cryogenic container ever manufactured for space flight.



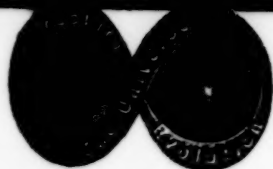
Spacecraft Assembly



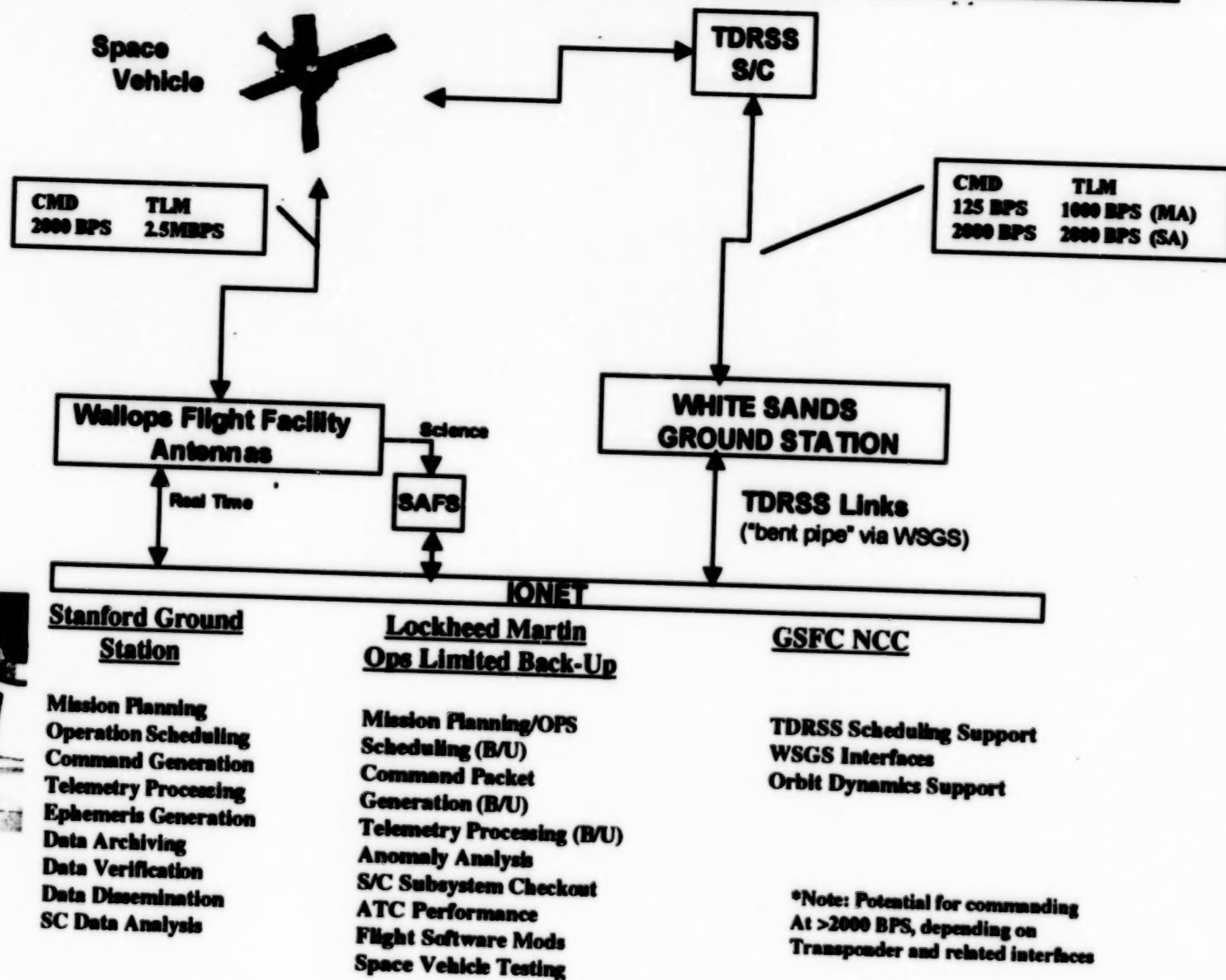
• Completed Spacecraft Systems:

- Power Distribution Unit
- Command and Telemetry Unit
- Interface Unit
- Solid State Recorder
- Magnetometer Electronics 1 & 2
- Command and Control Computer Assembly
- Standard Power Regulation Unit
- 5 of 7 Mass Trim Mechanisms (MTMs)
- Aft Rigid Plumbing
- +/- X Aft Thruster Tripods and Mounts

The Spacecraft is nearing completion as most subsystems have been delivered, tested, and integrated.



Operations Concept

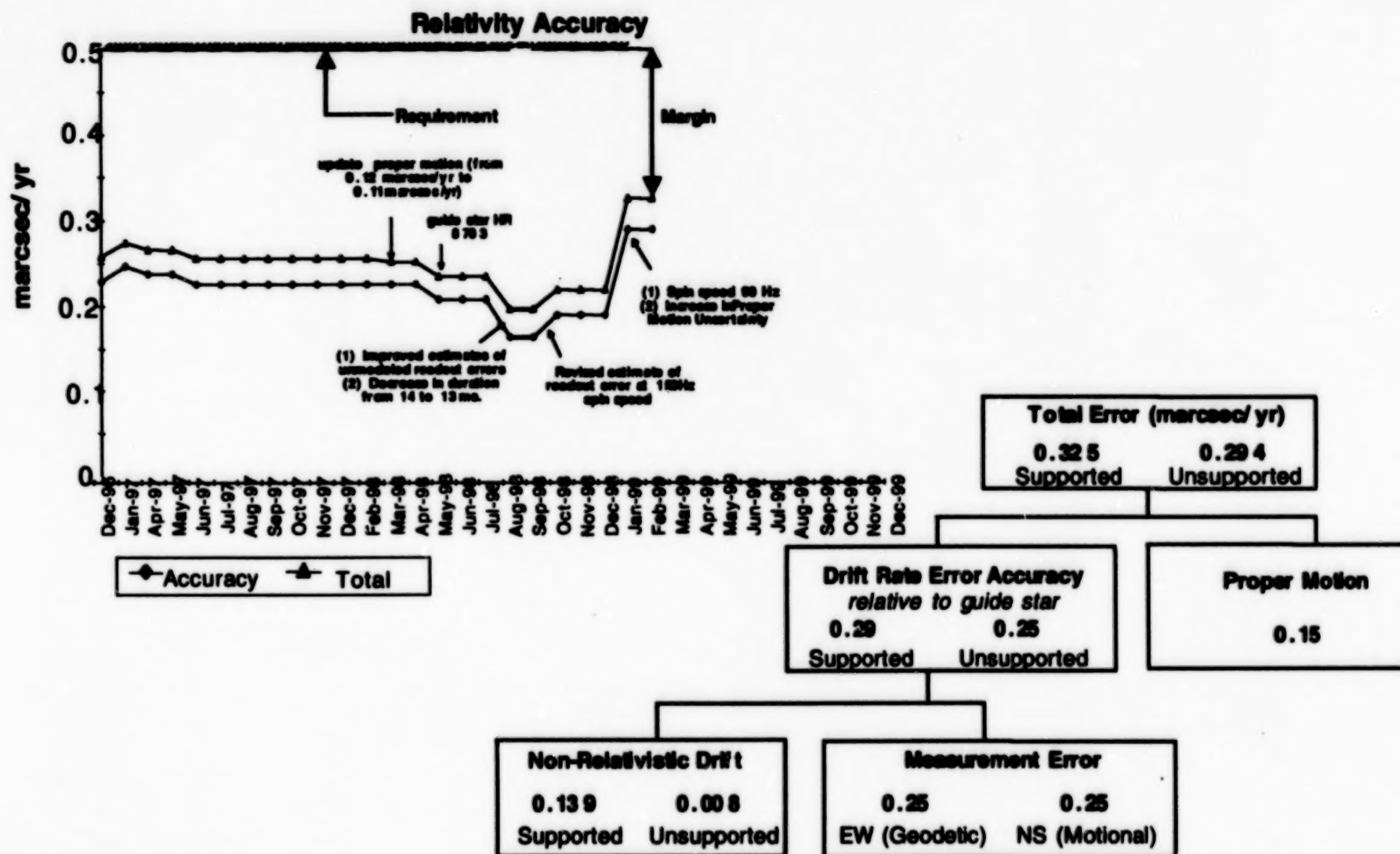




Status

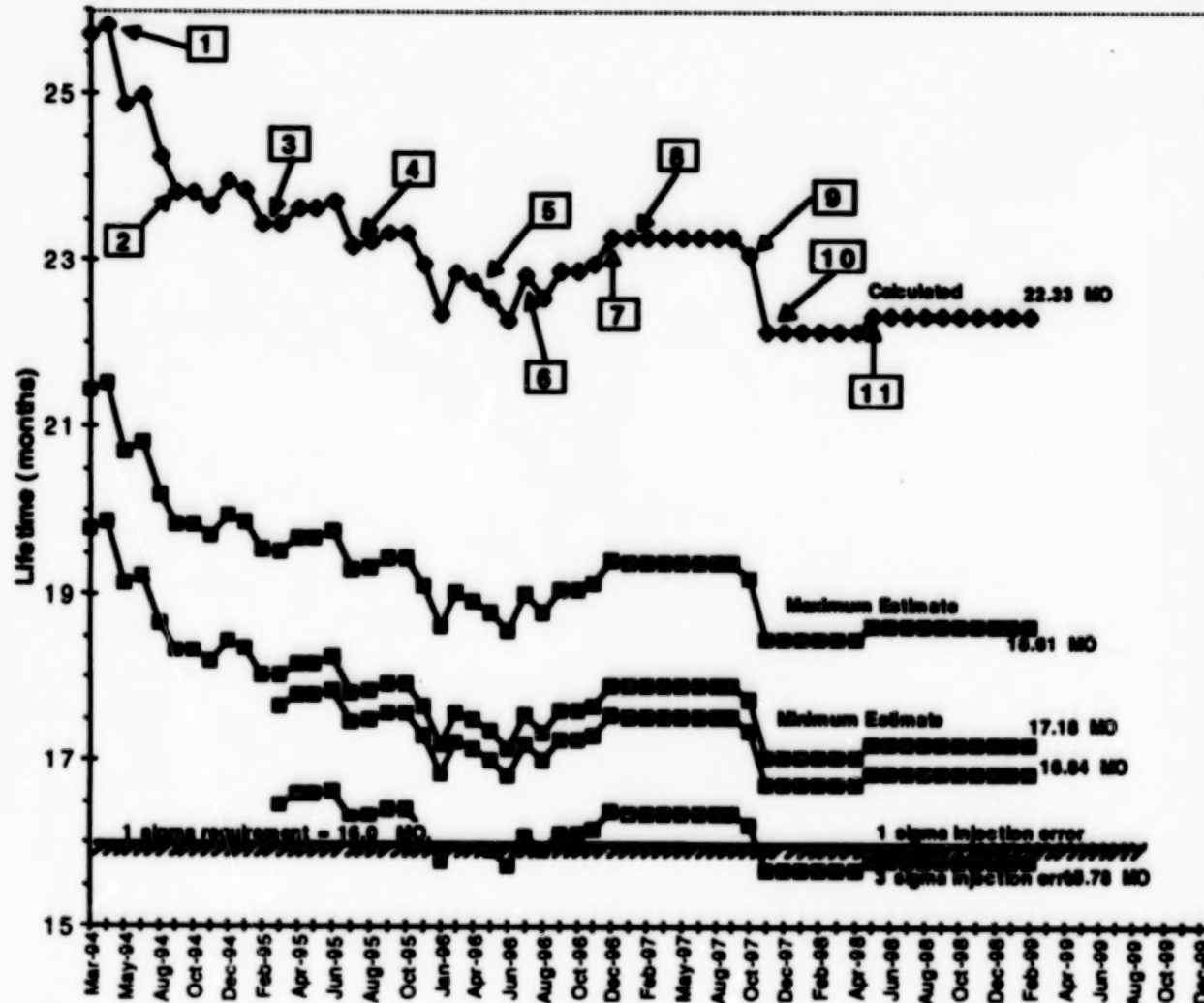
- **Science Instrument is complete.**
 - Telescope, Quartz Block, Gyroscopes, SQUIDs, etc.
- **Science Instrument to Probe Integration is complete.**
- **Probe-to-Dewar Integration is the next step.**
- **Spacecraft Integration is ongoing.**
 - Aft wiring harnesses nearly complete
 - Most spacecraft boxes are delivered, tested, and integrated
- **Payload Operations Center at Stanford is functional.**
 - I/O Net Connection Installed
 - Computers and Ground Software Installed
- **A functional version of the flight software is released.**
- **System Level Integration & Test is imminent.**

Key Technical Performance Measures: Overall Experiment Error





Key Technical Performance Measures: Dewar Lifetime



LEGEND

Calculated:

Basic calculation with no contingency applied

Maximum Estimate:

17% contingency applied, test data used for dewar
No Orbit trim

Minimum Estimate:

30% contingency applied for both probe and dewar
No Orbit trim

1 Sigma Injection

Error:

30% Contingency (min estimate)
With Orbit Trim
(14 days to trim)
Requirement is reduced on a pro-rata basis for orbit trim

3 Sigma Injection

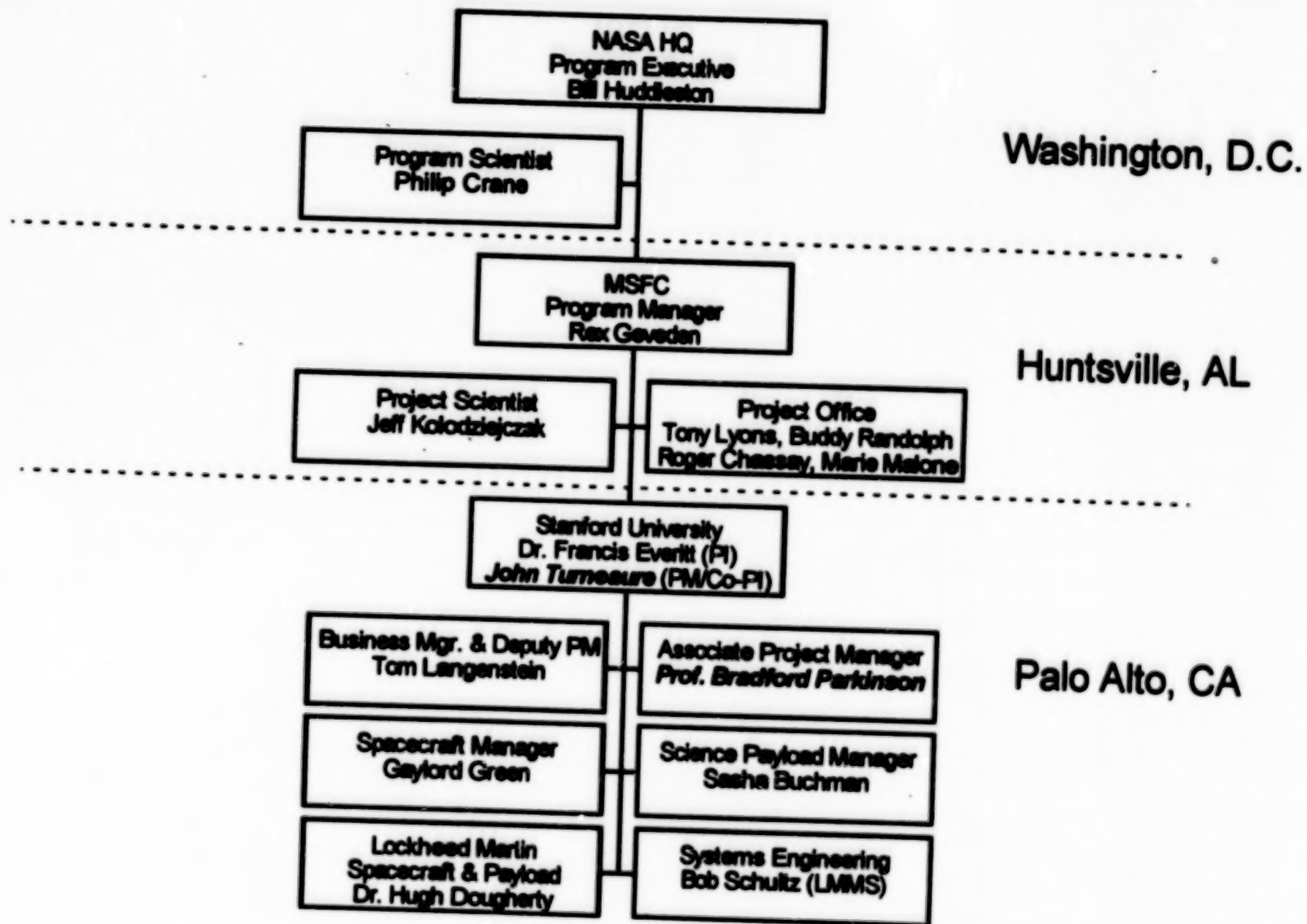
Error:

30% contingency (min estimate)
With Orbit Trim
(64 days to trim)

- | | |
|----|---|
| 1 | SMD CDR |
| 2 | Updated dewar wires |
| 3 | Updated probe wires |
| 4 | Changed emissivity of gold coatings, all 4 windows |
| 5 | Updated Skin temps: 233.5K-neck, 216K-fwd cone, 226.5K-mid cyl, 232K-aft |
| 6 | Updated neck temp to 242.9K to reflect moving some electronics aft to fwd |
| 7 | Reduce no. of SQUID cables from 24 to 18 |
| 8 | Corrected VCS conductance |
| 9 | PODS#2 short |
| 10 | All aft PODS short |
| 11 | 2 K decrease to vacuum shell temp. (first presented in 5/98) |

FIG13

Organization





GP-B Budget

PROGRAM COST COMMITMENTS (PCC), \$M											
FOR											
Relativity Mission/Gravity Probe -B											
COST COMMITMENT CATEGORIES	PRIOR	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	BTC	Totals	Responsible AA Signature
DEVELOPMENT (DCC)											
Phase B	20.4									20.4	
Phase C/D	310.5	57.3	46.5	25.7	5.4					445.4	
Totals	330.9	57.3	46.5	25.7	5.4			0.0	0.0	465.8	
OPERATION											
Phase E					9.1	6.3	4.1			19.5	
OTHER											
Coff										0.0	
Launch Services	10.6	13.5	14.8	14.8						53.7	
Tracking & Data										0.0	
Totals	10.6	13.5	14.8	14.8	0.0	0.0	0.0	0.0	0.0	53.7	
Totals (PCC)	341.5	70.8	61.3	40.5	14.5	6.3	4.1	0.0	0.0	539.0	

NOTES:

All figures reflect the FY 2000 PFP and the revised FY 1999 Operating Plan.

Note: This budget does not support the GP-B Baseline Program.

- Shortfalls: FY00: \$8.8M, FY01: \$7.5M.
- There is no schedule or budget reserve in this budget.
- The Program Office budget request in this POP cycle would provide for \$3.45M in risk management reserves, and 1.5 months schedule reserve.



Top Concerns

- **Budget**

- Issue: The POP guidelines do not adequately fund the GP-B Baseline Program.
- Resolution: Program Office POP submit will request \$18.1M above guidelines
 - > \$17.4M: Restoration of prior cuts
 - > \$0.7M: Education & Public Outreach (new requirement)

- **Schedule Erosion**

- Issue: The schedule margin is about 1.5 months against the October, 2000 launch.
- Resolution:
 - > Critical path items are being worked on a seven-day schedule
 - > To the extent possible, manpower is being shifted to critical path items
 - > Exploring an option to "buy" 6-day work schedule during space vehicle testing.
 - > Some integration has been delayed to maintain slack.

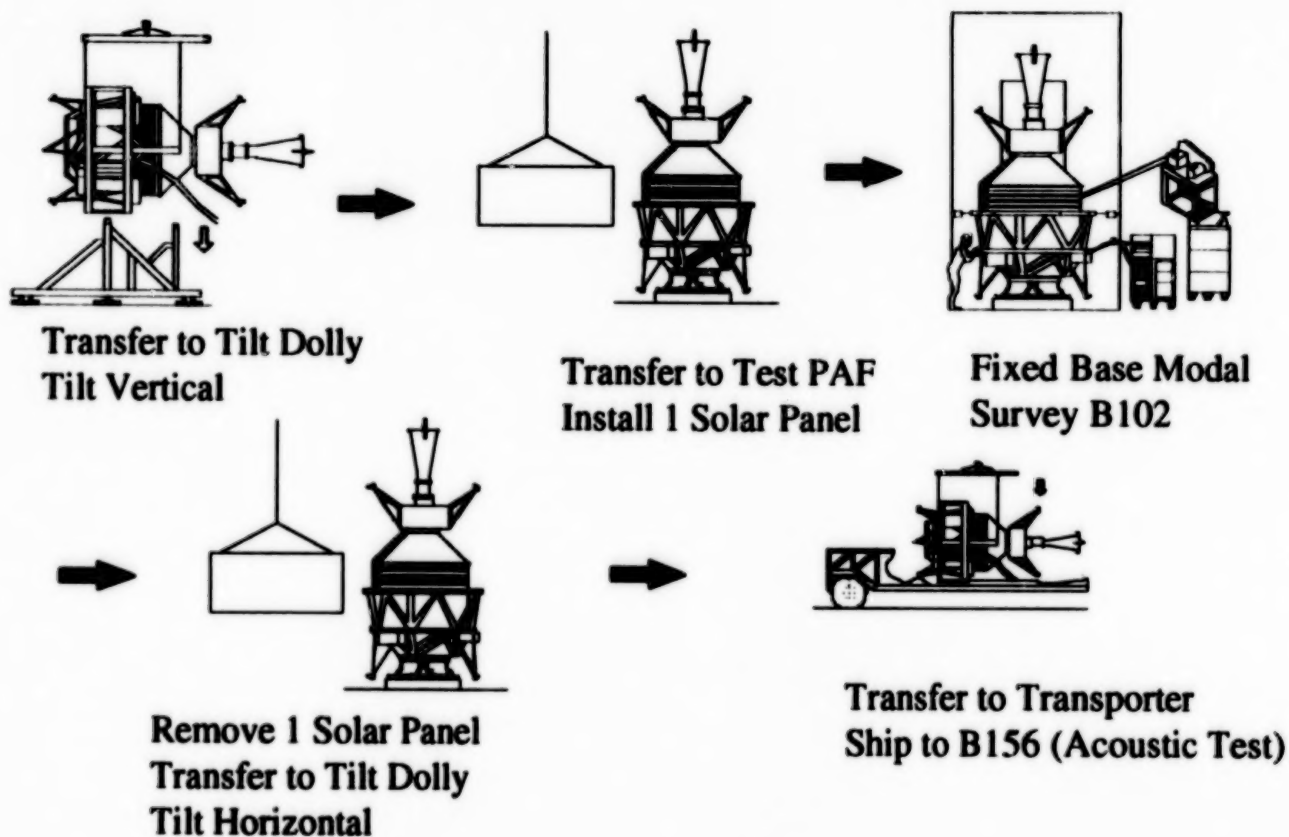
- **Particulate Contamination in Gyros**

- Issue: Contamination can destroy gyro performance and require a system recycle
- Resolution:
 - > System Recycle Risk Management Plan developed.
 - > Risk Mitigations being systematically undertaken.



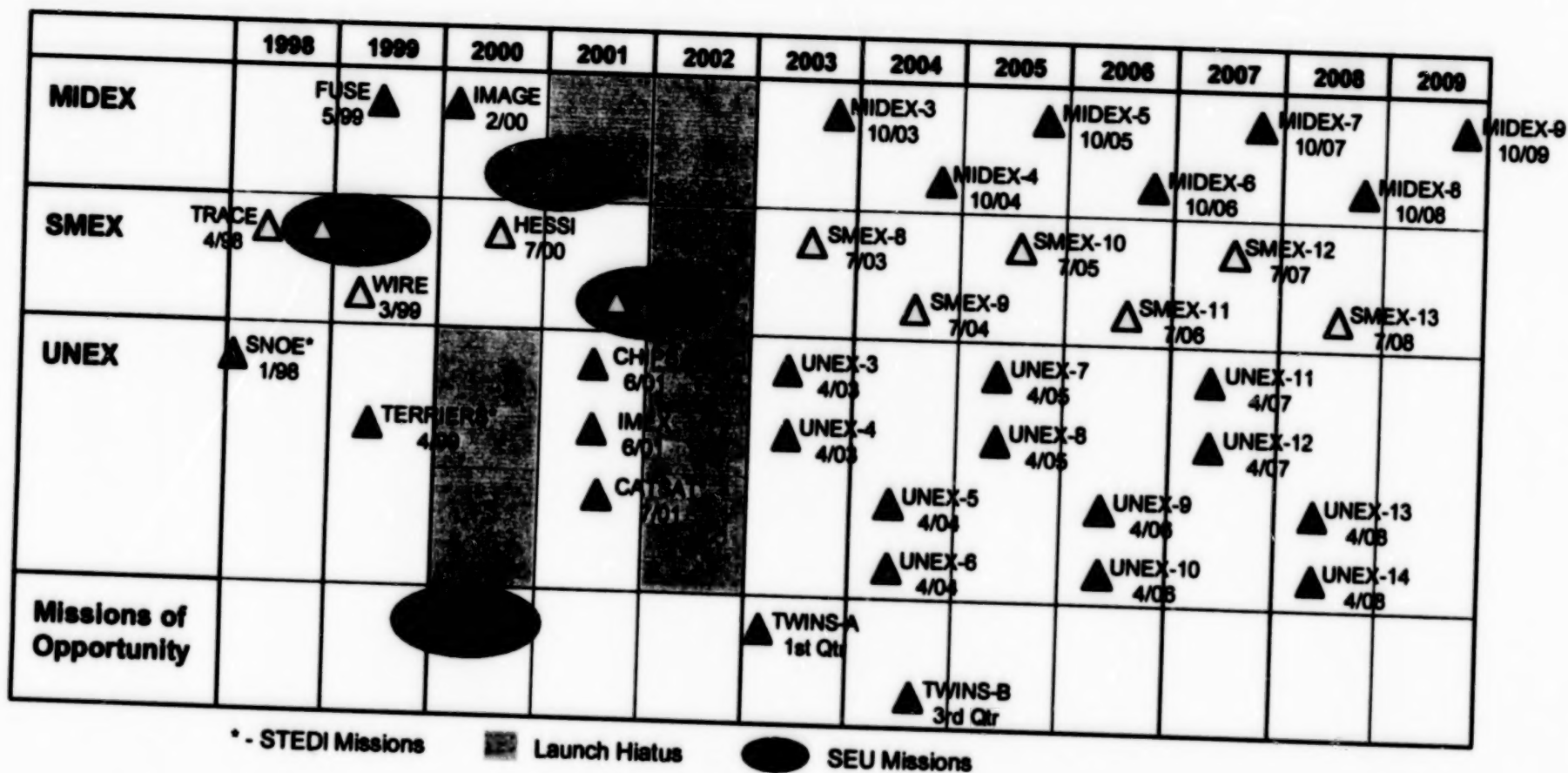
Outlook: Where Will GP-B Be in One Year?

- Payload Testing will be complete.
- Spacecraft to Payload Integration will be complete.
- Space Vehicle environmental testing will be underway:



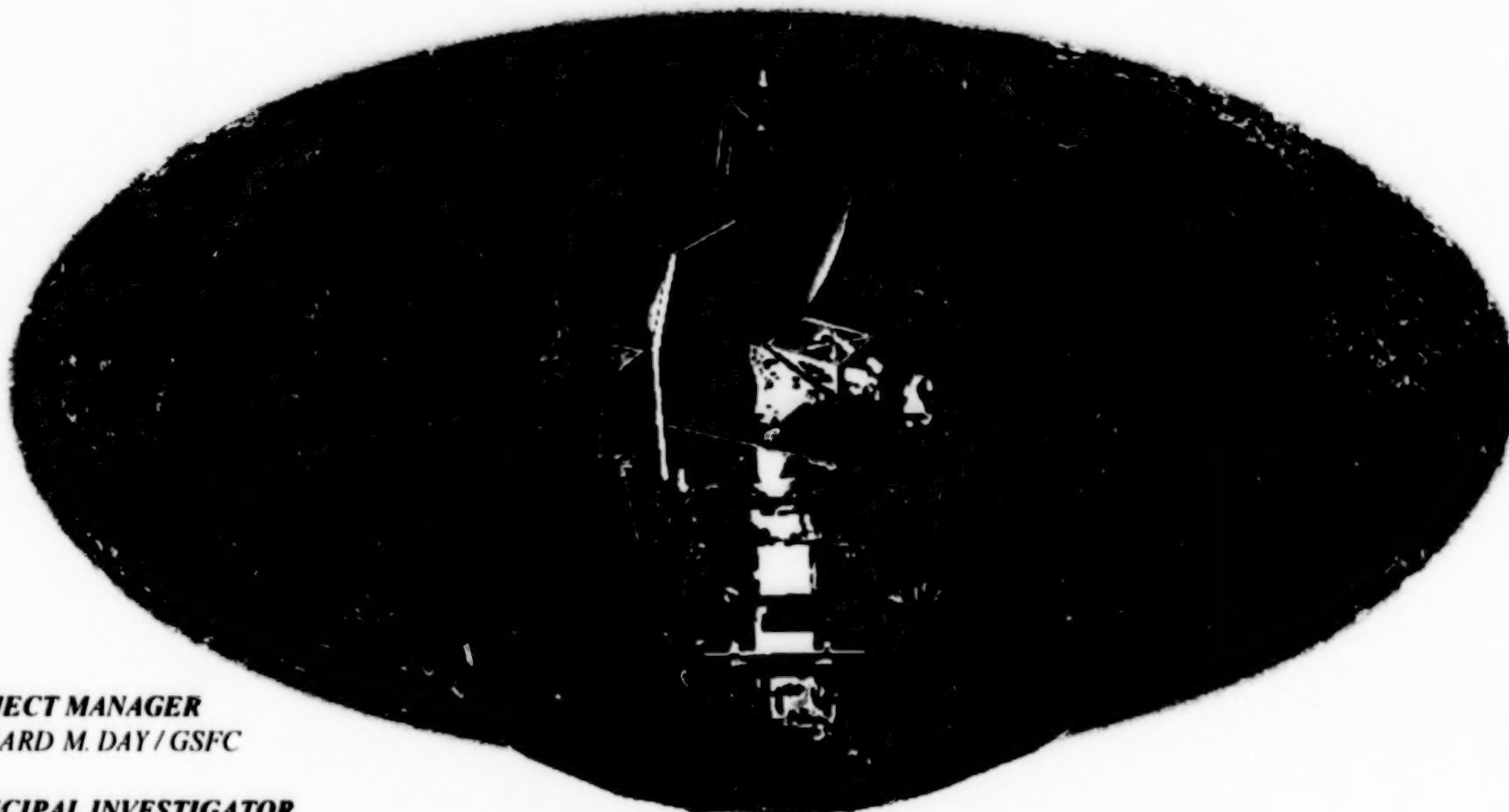


Explorers POP 99-1: Launch Schedule





Microwave Anisotropy Probe (MAP)



PROJECT MANAGER
RICHARD M. DAY / GSFC

PRINCIPAL INVESTIGATOR
CHARLES L. BENNETT / GSFC

PARTNER / MAJOR CONTRACT
PRINCETON UNIVERSITY

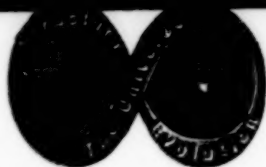
<http://map.gsfc.nasa.gov>

MAP 1

James S. Barrowman
GSFC / Explorers Program Office

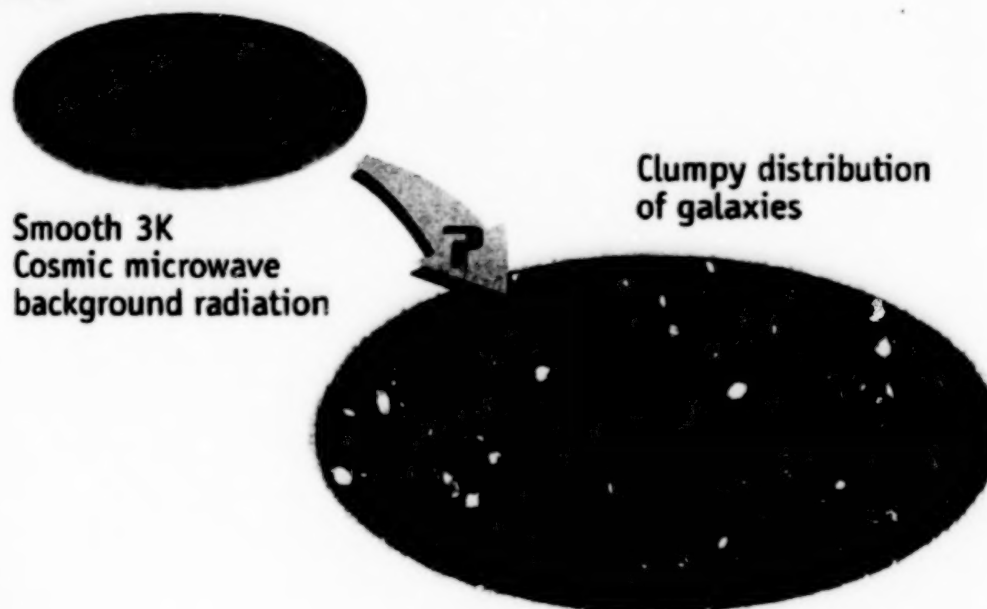
MAP

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Overview of the Science

- How did structures of galaxies form in the universe?



$\Omega_0 > 1$

$\Omega_0 < 1$

$\Omega_0 = 1$

- What are the values of the key parameters of the universe?



Driving Science & Engineering Requirements

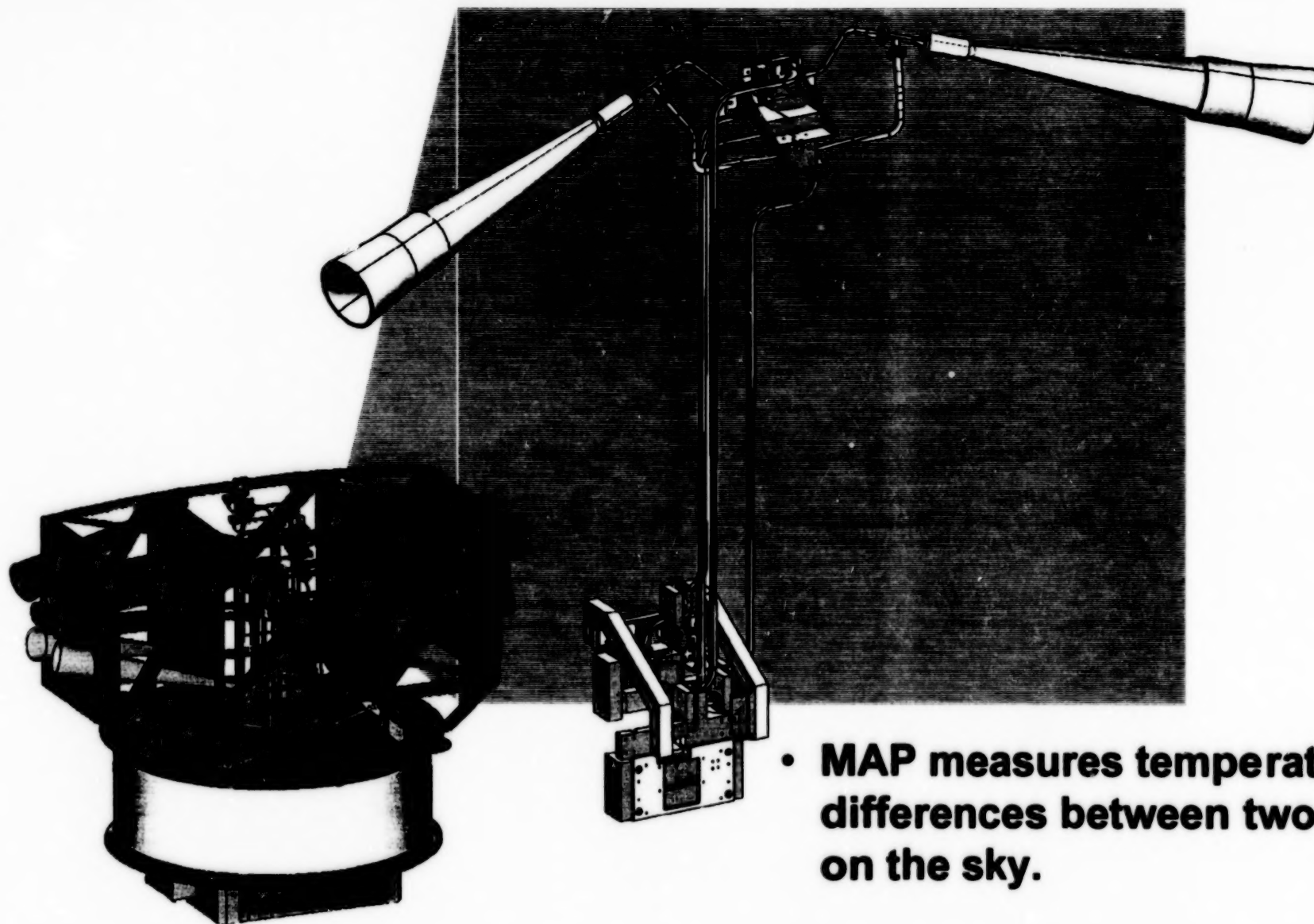
- **Minimize and control systematic error sources so they don't contaminate the part-in-a-million(!) measurements**

Quality Space CMB Mission Features	MAP
Full Sky Map	✓
True Map (Pixel Information Uncorrelated By The Instrument)	✓
Symmetric & Differential Observations	✓
Multiple Signal Modulations On Diverse Time Scales	✓
Rapid Large-Sky-Area Scanning	✓
Fully Developed Systematic Error Budget	✓
Very Low Sidelobe Beam Patterns	✓
No Atmospheric Contamination	✓
Extreme Thermal Stability With No Active Controls	✓
Self-Calibrating	✓
Minimize Microwave Down-Link Transmitter "On" Time	✓
Multiple Channels	✓
Multiple Frequencies Near CMB-to-Galactic Signal Spectral Maximum	✓

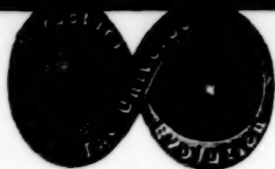
- **rms sensitivity of 20 μ K per pixel (400,000 pixels),
systematic errors < 4.5 μ K, calibration accuracy < 1%,
angular resolution 0.2°, polarization sensitive**



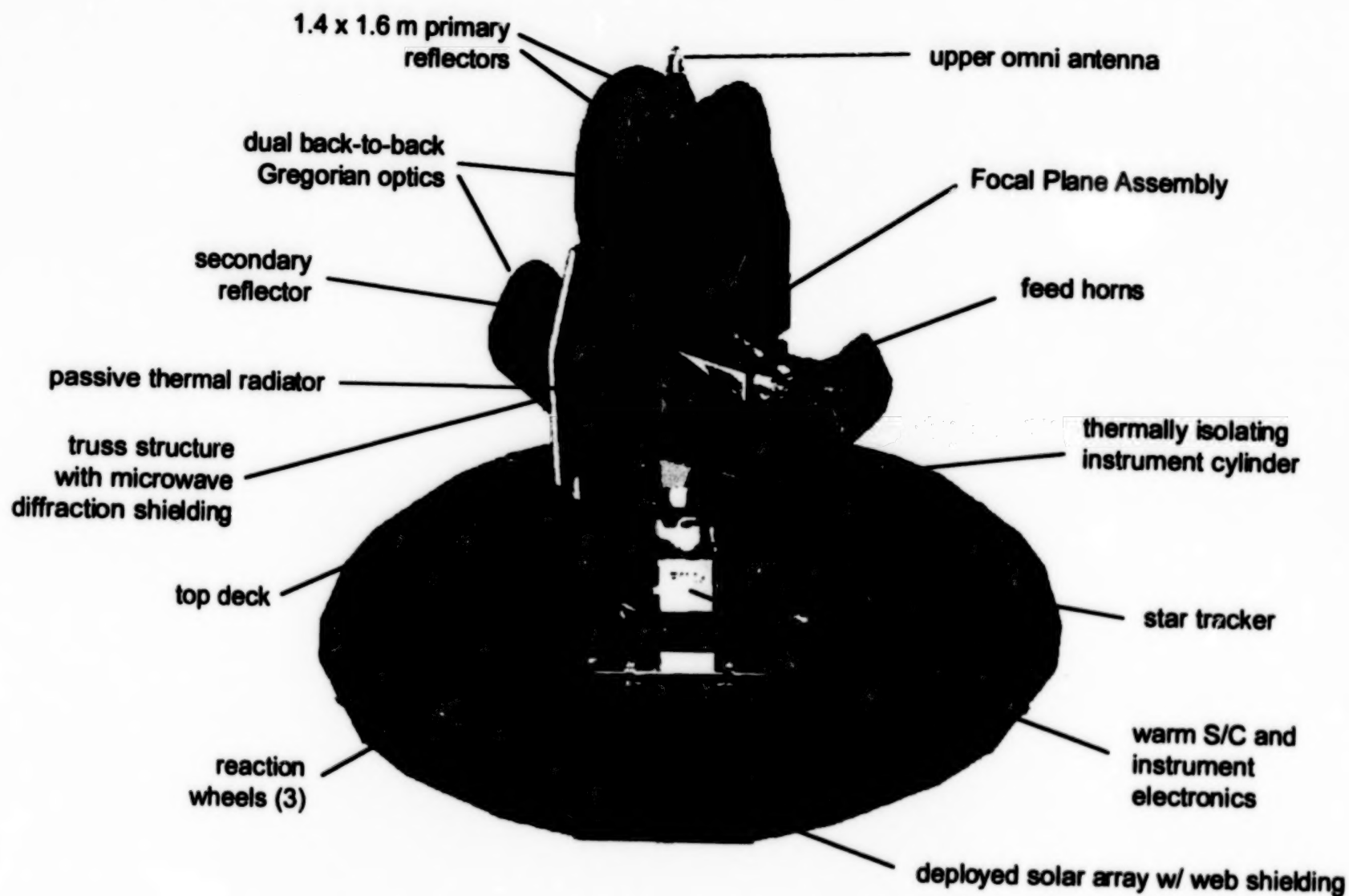
MAP Microwave System



- MAP measures temperature differences between two points on the sky.



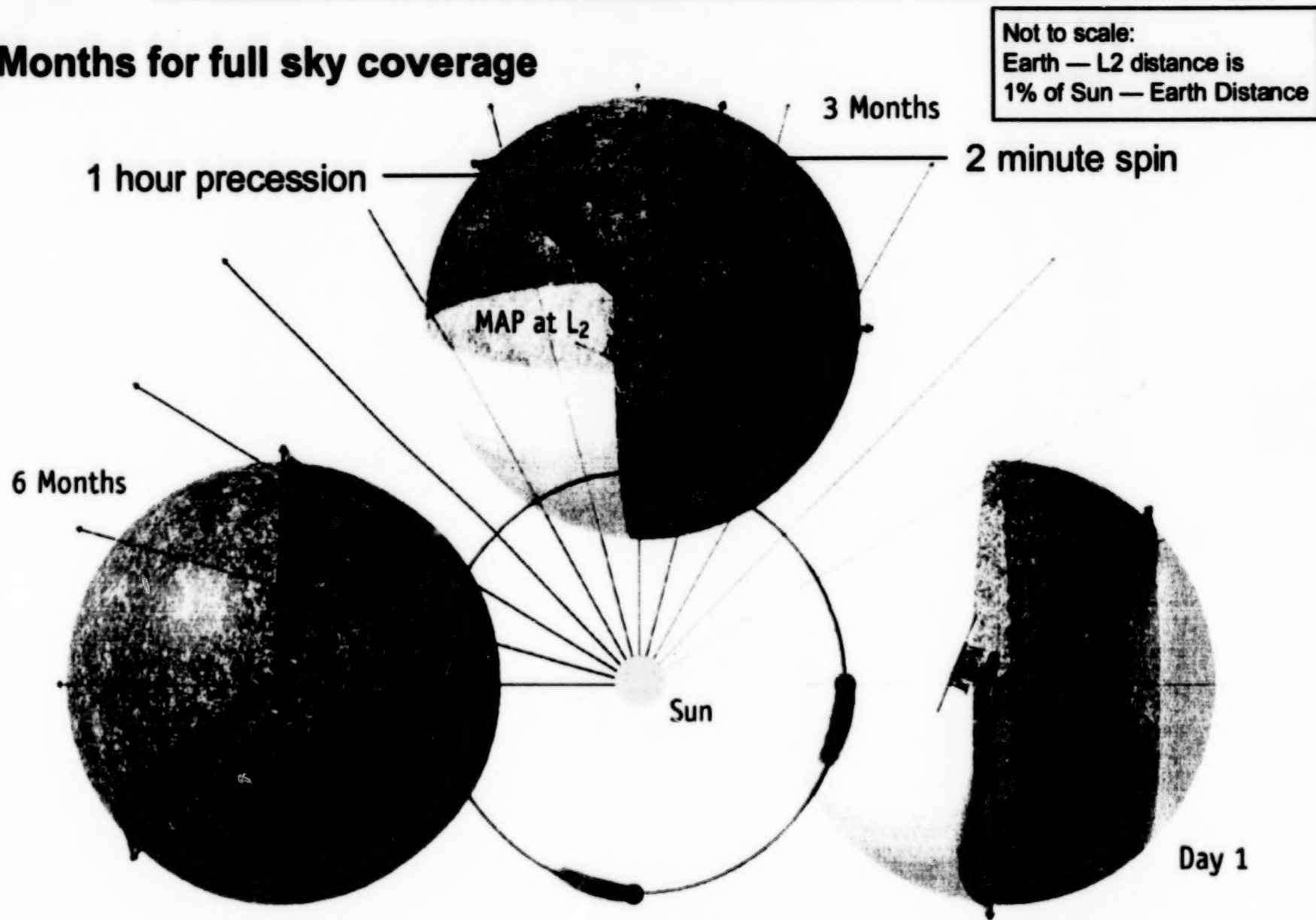
MAP Observatory





Scan Strategy

- 6 Months for full sky coverage





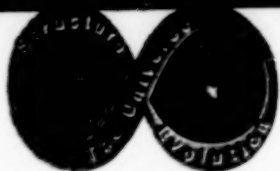
Project Status

- **Instrument integration is in progress at GSFC**
 - Princeton University has delivered all flight differencing assemblies and microwave feeds
 - Instrument electronics units have been delivered
 - Composite microwave optics and support structure (thermal reflector system) is in acceptance testing
- **Spacecraft integration is in progress at GSFC**
 - Integrating propulsion system and harness to composite structure
 - Components delivered or in final stages of production
- **Operational ground system is in place at GSFC**
 - Supporting component, instrument and spacecraft - level integration & test and flight/ground software development and acceptance testing
 - IMAGE and EO-1 have leveraged this development



Budget

- **Development Capped Cost of \$88.3M**
 - Instrument Development Cost \$50.3M (57%)
 - Spacecraft Development Cost \$38.0M (43%)
 - Reserves \$4.1M (11% of cost to complete)
- **MO&DA Capped Cost of \$11.4M**

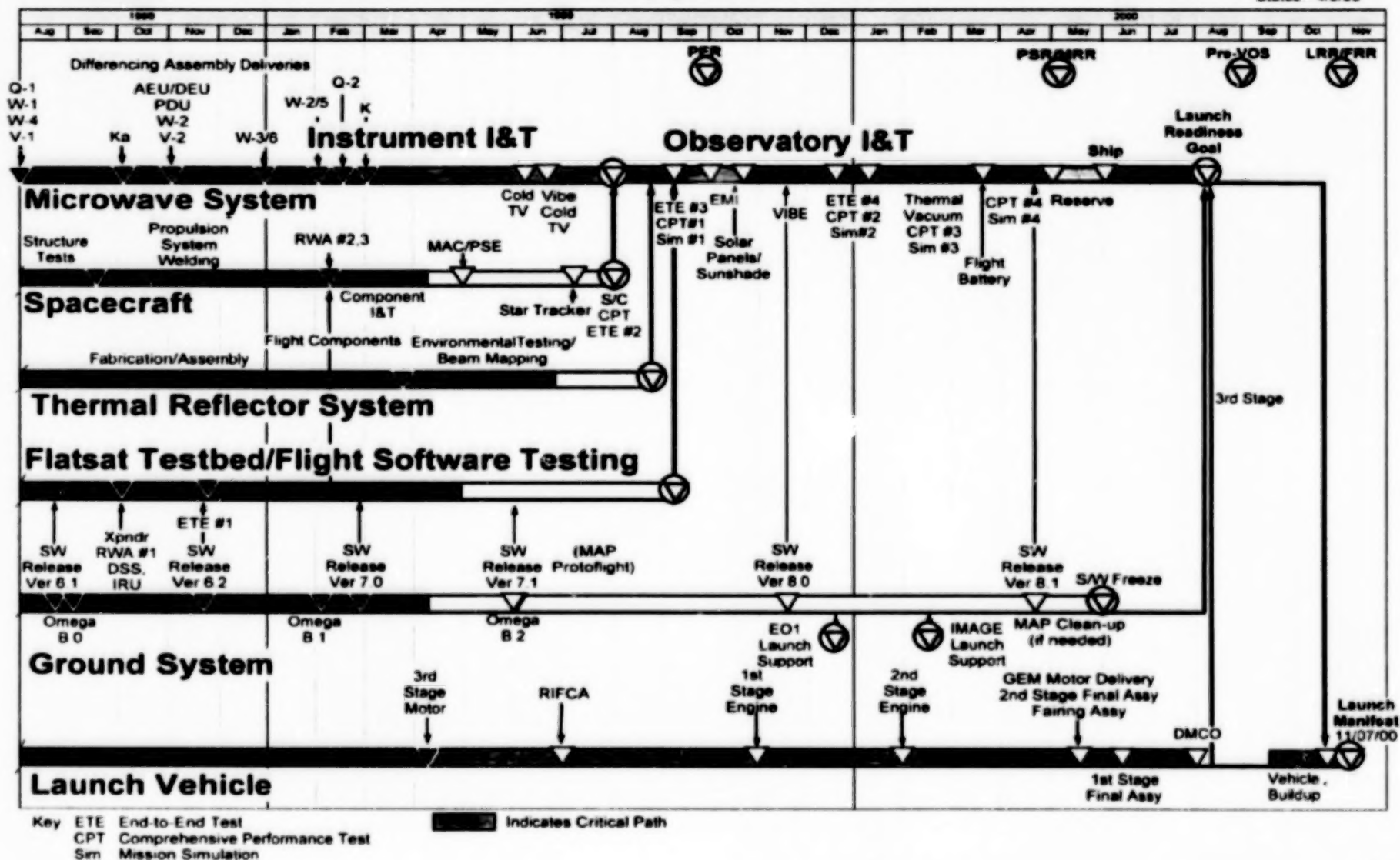


Schedule



Microwave Anisotropy Probe Master Schedule

Revised: 4/9/99
Status: 4/9/99





One Year Outlook

- **1 year from now, MAP will be preparing for shipment to the launch site**
- **Launch on a Delta 7425 planned for 11/2000**



MAP is Rated Top-Priority

ASTRONOMY

Follow Up on Findings, Panel Tells NASA

A panel of astronomers is urging NASA to follow up quickly on the field's recent successes. Convened by the National Research Council (NRC) at NASA's request, the 50-member panel, chaired by Patrick Thaddeus of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, has urged NASA to give priority to space-based instruments that would build on some of the most exciting finds of recent years: the mapping of the cosmic microwave background, the discovery of galaxies in the early universe and planets around other stars, and the detection of objects that are almost certainly black holes.

The panel, which briefed NASA space science head Wesley Huntress on 8 April and will formally present its report in a month, did not draw up a wish list of instruments. Instead, it described the areas of science that should receive top priority in NASA's space science plans. "We picked the science ideas that have staying power," says Thaddeus, but its recommendations give a boost to several missions planned, from new ground-based observatories to the Hubble Space Telescope.

program director in NASA's Office of Space Science. "I've needed priorities—and we needed them in a hurry about time scale." To speed things along, the NRC panel, convened just a year ago, debated research priorities in space science only.



Eagerly awaited. The MAP mission will chart details of the microwave background radiation.

At the top of the list for the next 10 years or so, said the committee, is refining a map of the microwave background radiation. In the early 1990s, the Cosmic Background Explorer revealed tiny temperature variations in this uniform bath of microwaves—the imprint of primordial "seeds" that grew into great structures in today's universe. A finer scale map of these ripples would yield clues not just to structure formation but

to the long-sought final state of the universe. Thaddeus and his colleagues say—implicitly nudging NASA to keep a planned satellite called the Microwave Anisotropy Probe (MAP) on track for a 1999 launch. The report also calls for more observations on recent spectacular galaxy near the

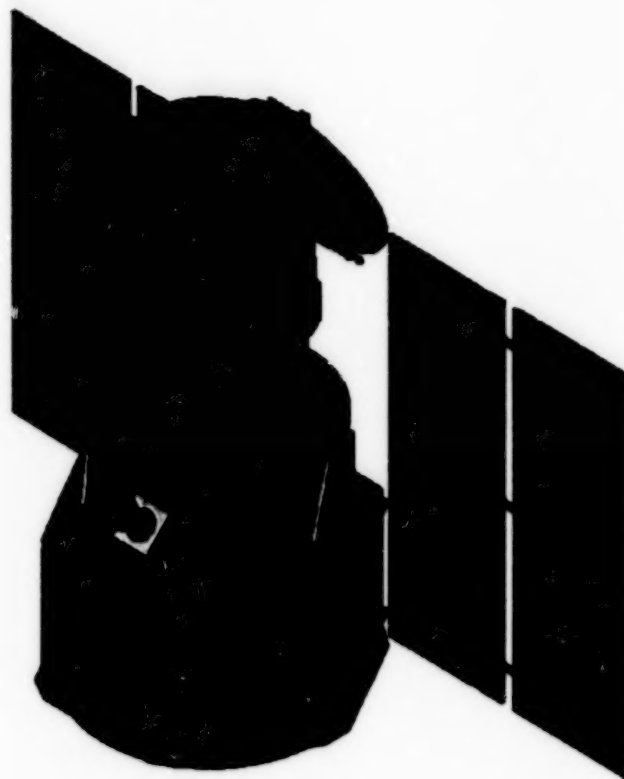
"At the top of the list... is refining a map of the microwave background..."

"Eagerly awaited"

"...nudging NASA to keep a planned satellite called the Microwave Anisotropy Probe (MAP) on track..."



GALaxy Evolution Explorer (GALEX)



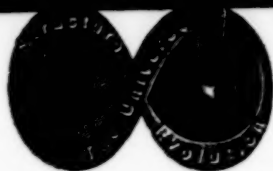
PROJECT MANAGER
FRANK SNOW / GSFC

PRINCIPAL INVESTIGATOR
CHRIS MARTIN / CALTECH

PARTNER / MAJOR CONTRACT
JET PROPULSION LAB (JPL)
ORBITAL SCIENCES CORP (OSC)

<http://www.srl.caltech.edu/galex>

James S. Barrowman
GSFC / Explorers Program Office



Science Goals

- **Goal 1: Local UV Universe**

- What are the UV properties of local galaxies, and how do rest UV properties, measured at high redshift by HST and NGST relate to star formation rate (SFR), extinction, metallicity, and burst history

- **Goal 2: Star Formation History -- $0 < z < 2$**

- What is the star formation and metal production history of galaxies over the redshift range $0 < z < 2$? When and where did stars and elements we see today have their origins? And does this history explain the dramatic evolution suggested in previous surveys?

- **Goal 3: Global Causes of Star Formation & Evolution**

- Microhistory of star formation
- Star formation history vs. galaxy density
- Star formation and interactions
- Initial Mass Function evolution
- Star formation and gas content

GALEX Science Overview

A GALEX Science Overview—GALEX will map the global history and probe the drivers of star formation over the redshift range $0 < z < 2$, 80% of the life of the Universe, the period over which galaxies have evolved dramatically, and the time that most stars, elements, and galaxy disks had their origins.

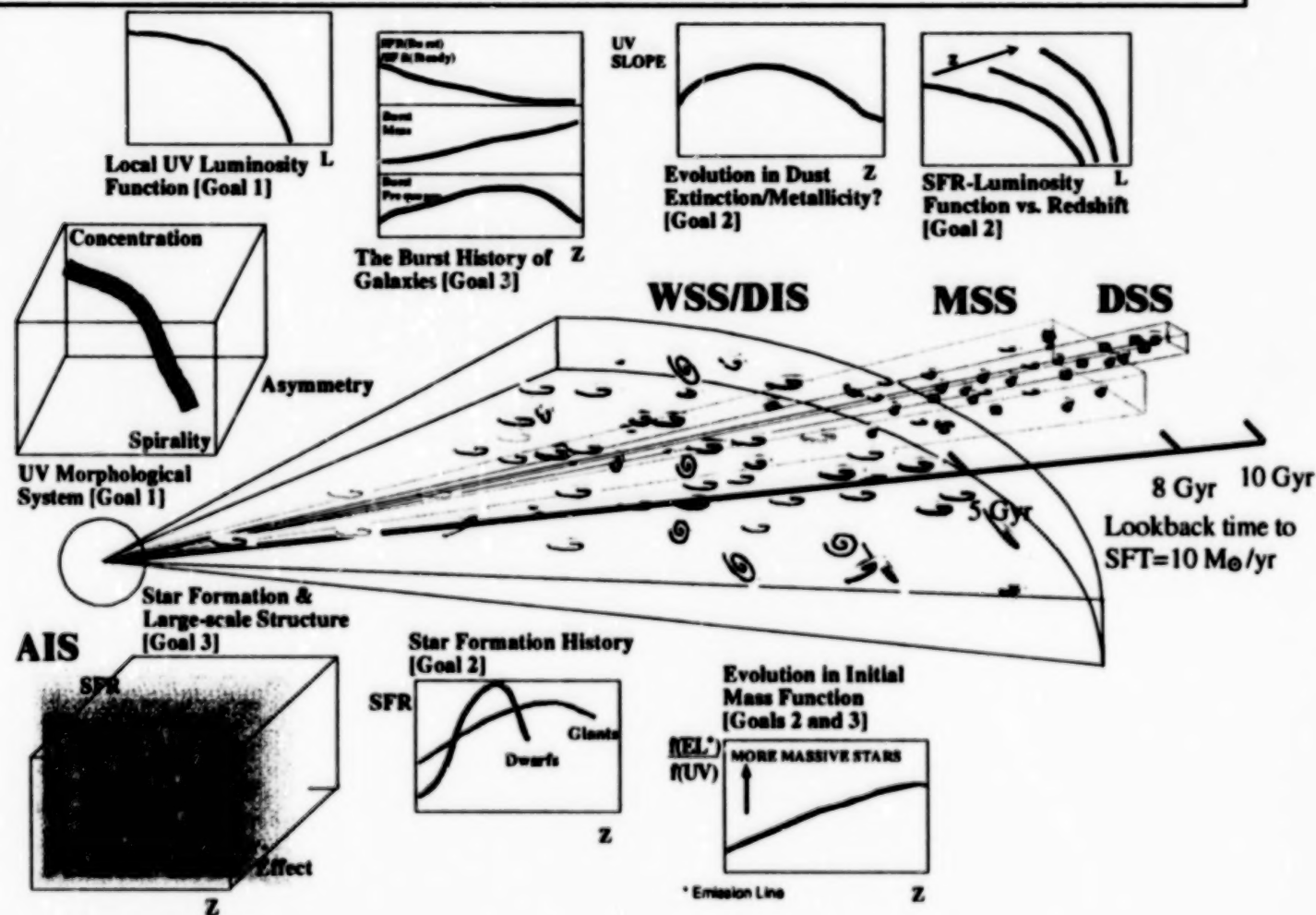
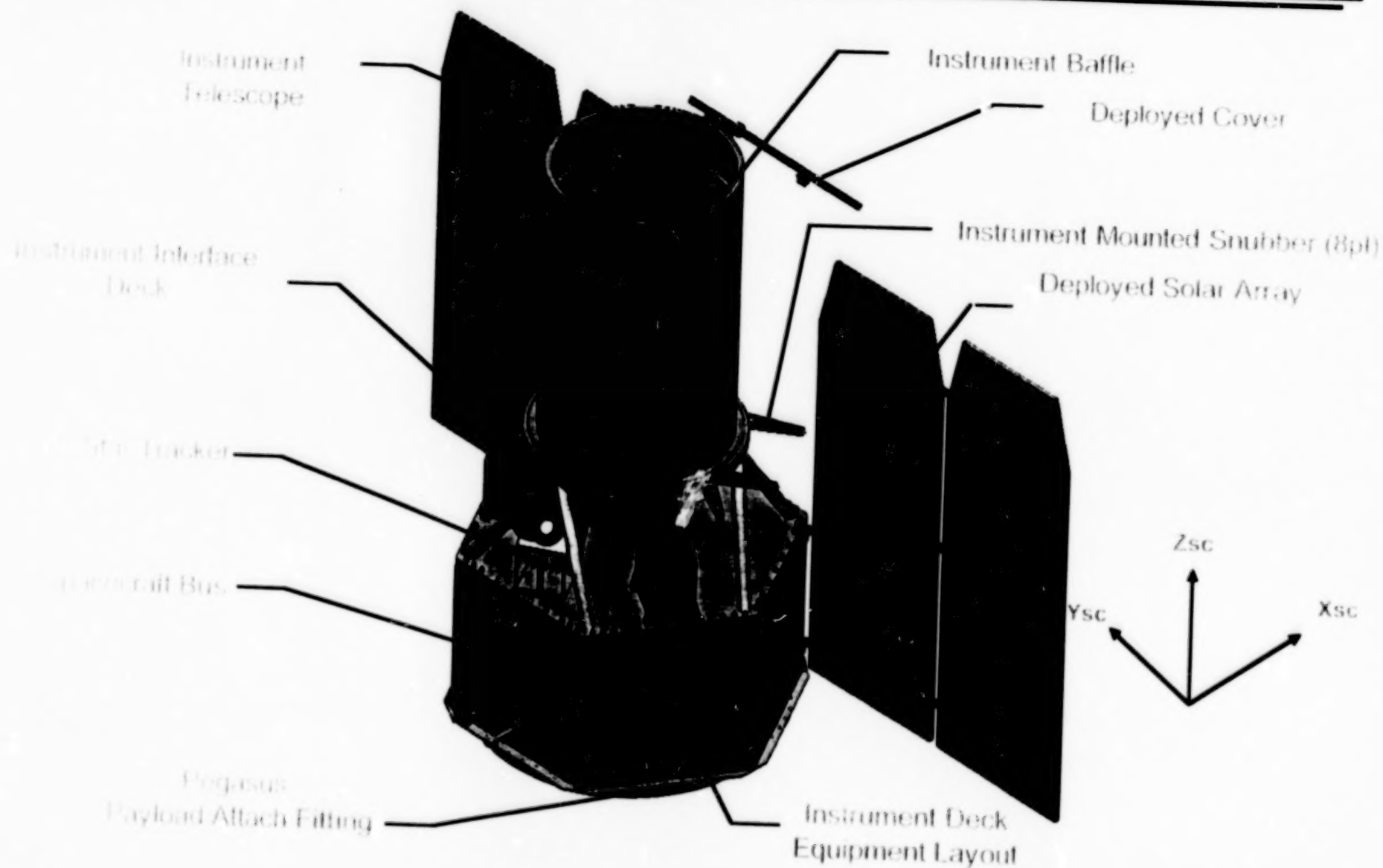


Table A-1: GALEX MISSION SUMMARY



Satellite Configuration





Mission Definition

- **Instrument:**

- UV 1350-3000Å, 50 cm telescope, 2 Microchannel Plate detectors, Rotating grism

- **Orbit:**

- 690km x 690km 29° inclination

- **Mass:**

- 313kg (capability) 256.5kg (CBE)

- **Launch:**

- September 5, 2001 from KSC Pegasus XL

- **Mission:**

- 28 month mission, nighttime exposures with 3-axis stabilized spacecraft
- All-sky survey and deep surveys



Mission Definition

- **Satellite**

- Instrument
 - > Detectors *(JPL performs I&T)*
 - > Structure/Mechanisms/BFA/DPU *University of California, Berkeley*
 - > Optical Elements *JPL*
 - > Optical Coatings *Laboratoire d'Astronomie Spatiale*
 - > Telescope Assembly *Caltech*
- Spacecraft *Lightworks Optics (FFP Contract)*
Orbital Sciences Corp.

- **Ground Segment**

- Mission Operations *Orbital Sciences Corp.*
- Science Operations and Data Analysis *Caltech, South Korea*
- Archive *Johns Hopkins University (Sloan Digital Sky Survey)*
- Science Downlink *University of Hawaii*

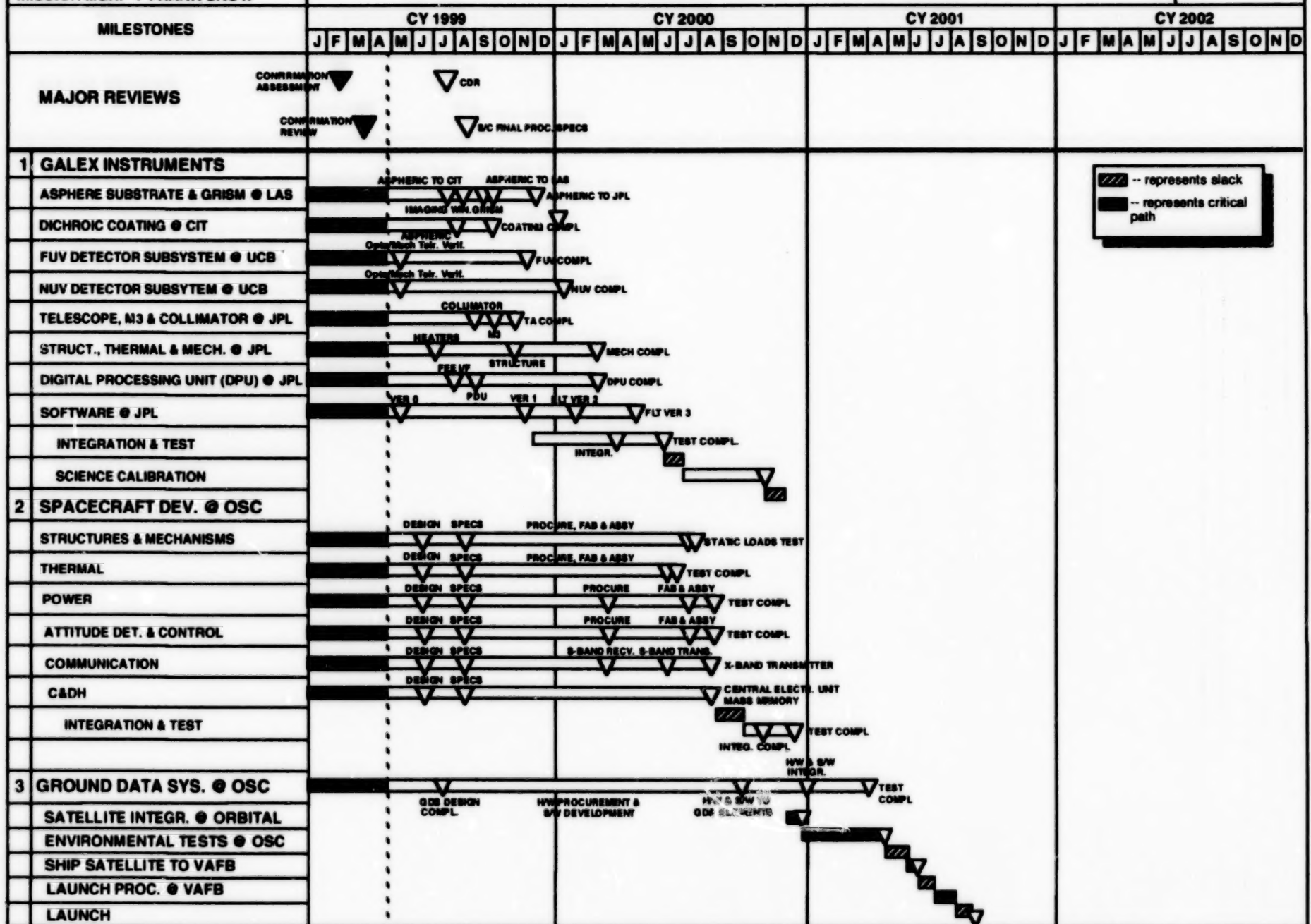
- **Delivery Segment**

- Launch Services *Kennedy Space Center*
 - > Pegasus XL Launch Vehicle *Orbital Science Corp. Launch Services Group*

GODDARD SPACE FLIGHT CENTER
 APPROVAL: J. BARROWMAN
 MISSION MGR. : FRANK SNOW

GALEX MISSION SCHEDULE

STATUS AS OF: 4/19/99





Status

- **Completed Formulation Phase April, 1999**
- **Mission CDR in July, 1999**

At this time next year we will be completing the Integration and Testing of the GALEX Instrument.



Budget

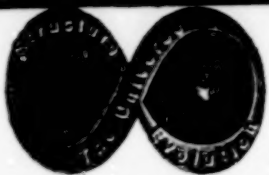
• NASA Funding	(\$MRY)
- Formulation and Implementation	39.3
- MO&DA	11.2
- Reserves	<u>5.0</u> [15.6%]
	55.5
• Contributions	
- Laboratoire d'Astronomie Spatiale, France	1.2
- South Korea, Ministry of Science & Technology	<u>0.5</u>
	1.7
• TOTAL	57.2



Top Risks

- **Schedule**

- Concerns
 - > Sealed Detector Schedule (Dr. Siegmund @ UCB)
 - > Dependency on OrbView 4 Heritage (to be launched in 3rd Quarter, 2000)
- Mitigation
 - > Additional staffing @ UCB
 - > 5-6 weeks of funded schedule reserves
 - > GALEX risk identification plan is excellent and tightly coupled to descope plan



High Energy Transient Explorer-2 (HETE-2)

PRINCIPAL INVESTIGATOR

DR. GEORGE R. RICKER, MIT

PROJECT MANAGER

**GUSTAVE J. COMEYNE, JR.,
GSFC**

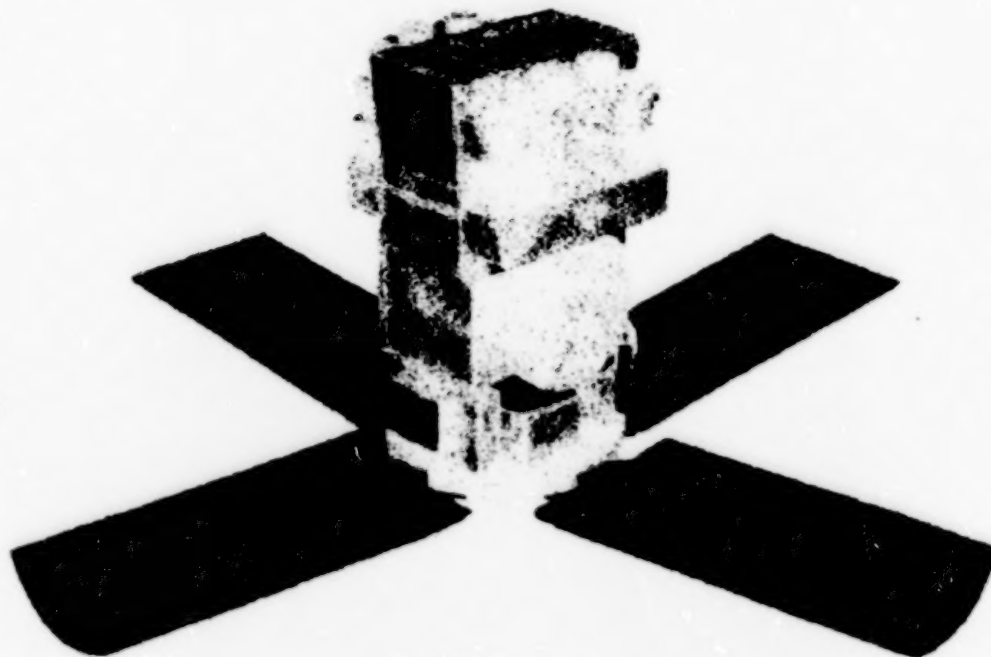
MAJOR PARTNERS

**THE INSTITUTE OF PHYSICAL
AND CHEMICAL
RESEARCH (RIKEN),
JAPAN**

**CENTRE d'ETUDE SPATIALE
des RAYONNEMENTS
(CESR), FRANCE**

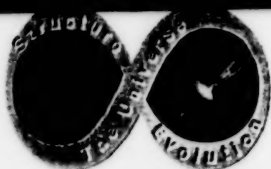
**LOS ALAMOS NATIONAL
LABORATORY**

[http://international.gsfc.nasa.gov/
International/Missions/Hete_2/
Hete_2.html](http://international.gsfc.nasa.gov/International/Missions/Hete_2/Hete_2.html)



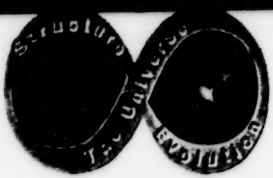
James S. Barrowman
GSFC / Explorers Program Office

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Overview of the Science

- **The original HETE was lost due to a Pegasus launch failure on November 4, 1996. The objectives of the re-flight HETE-2 mission include the simultaneous, broad-band observation of energetic, transient astrophysical sources in the soft X-ray, medium X-ray, and gamma-ray energy ranges, and the precise localization and identification of cosmic Gamma-Ray Burst sources (GRBs). The HETE-2 instruments-gamma-ray detectors, X-ray cameras, and soft X-ray cameras-will operate synergistically in order to:**
 - Identify the occurrence of a GRB.
 - Approximately locate the GRB (~10 arc minute accuracy) utilizing its medium energy X-ray emission.
 - Precisely locate the GRB (~10 arc second accuracy) utilizing its soft X-ray emission. Rapidly transmit (~10 second delay) the location and intensity data directly to ground-based optical, IR, and radio observers.
- **The precise HETE-2 location of a source of gamma-ray bursts can then be used by the worldwide community of astronomical observers in searches for the counterpart and its afterglow throughout the electromagnetic spectrum.**



Mission Definition

- **HETE-2 will retain nearly all of the original HETE design elements. A new feature of the spacecraft is the Soft X-ray Cameras, which take the place of the UV cameras. This was done in view of the recent results showing substantial photon fluence in the low energy X-ray band, and the possibility of achieving finer localization with a CCD/coded mask combination. Mission parameters are:**
 - Launch Date: 1/23/00 (optional launch date of 12/10/99 being assessed)
 - Payload: 3 science instruments
 - Orbit: Nominal 600 km x 650 km orbit at an inclination of less than 5 degrees, but with a desired goal of less than 2 degrees
 - Design Life: minimum mission lifetime of 6 months with a goal of 2 years
 - Diameter: 0.86 Meters
 - Length: 0.97 Meters
 - Weight: 150 Kilograms
 - Launch Vehicle: Hybrid Pegasus, launched from Kwajalein Missile Range (KMR)
 - International Participation: France and Japan for instruments and primary/secondary ground stations, Italy for a secondary ground station



Status

- The Wide-Field X-Ray Monitor (WXM) supplied by RIKEN, Japan and the French Gamma Telescope (FREGATE) supplied by CESR, France have been delivered and integrated onto the spacecraft.
- The flight Soft X-Ray Cameras (SXC) from MIT are in fabrication.
- HETE-2 spacecraft is being assembled and tested at MIT. Engineering Model SXC being used until Flight Model SXC is integrated in early June.
- HETE-2/Pegasus Interface Control Document released.
- HETE-2 Accident Risk Acceptance Report (safety report) submitted for review.



Budget

- **HETE-2 mission capped at \$21.9M**
 - Launch Vehicle \$13.5M
 - HETE-2 Spacecraft \$8.4M
 - Current reserve \$0.3M (10% of cost to complete)
- **Mission Operations and Data Analysis**
 - NASA HQ funded at NTE cost of \$3.0M for 16 months



HETE-2 Schedule to Launch

<u>Activity</u>	<u>Completion Date</u>
Flight Power Box Test	4/21/99
Spacecraft "final" Assembly	4/28/99
Integrate Flight SXC	6/5/99
Functional Tests	6/16/99
First set of Mission Sims	7/22/99
Vibration Test	7/29/99
Thermal Vacuum Test	9/7/99
Second set of Mission Sims	10/20/99
Ship to VAFB	12/1/99
Ready to Integrate to Pegasus	12/14/99
Launch from KMR	1/23/00



Issues

- **Concern**

- At time of launch, Stage 1 and 2 solid motors will be nearly 7 years old
(Contract from Orbital with Alliant allows 7 years)

- **Programmatic Impact**

- Flight acceptable of the standard Pegasus Stage 1 and 2 motors after lengthy storage

- **Action**

- Acceptance review of Pegasus motors at Alliant scheduled for late April/
early May



END

05-07-03